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A Study of Instrumental Method for Suiting Fabric Hand Evaluation and Classification

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A Study of Instrumental Method for Suiting Fabric Hand Evaluation and Classification

by

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A STUDY OF INSTRUMENTAL METHOD FOR SUITING FABRIC HAND EVALUATION AND CLASSIFICATION

by

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In the textile and apparel industry, fabric end-use preference and selection criteria are largely based on fabric hand because it relates to both the mechanical properties and aesthetic appearance of fabrics. This paper examines a method to grade fabric hand based on Kawabata's measurements and neural network modeling. The proposed method is verified by comparing the hand graded by the neural network model to Kawabata's total hand value. Ninety-five commercial fabrics from different manufacturers were tested using Kawabata evaluation system (KES-FB). Cluster analysis using SAS classified the suiting fabric samples into four groups in this study.

The test results of fabric mechanical properties show similarities and dissimilarities between woven and knitted suiting fabrics. In comparison, woven suiting fabrics are less subject to shear and bending deformation. Knitted fabrics have a higher total hand value than woven fabrics with a smoother surface. Cluster analysis well divided the suiting fabric samples into four groups describing different fabric performance. The training dataset in the neural network model was selected based on information from the clustering results.

The training model was proved to be accurate with a low MSE of 4×10^{-8}. The model successfully graded the test samples with values ranged from 0 to 1. Additionally, the validity for grading fabric hand using the neural network technique was examined by analyzing the correlation between the hand graded by neural network model and Kawabata's equations. The regression analysis shows a relatively strong correlation ($p<0.0001$, $R^2= 0.6363$) between neural network grades and Kawabata's grades.

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Chapter 1 Introduction

1.1 Introduction

Fabric hand is one of the most important end-use properties of apparel fabrics. Hand or handle implies the tactile sensory in response to fabric feeling by hand. It has been defined by The Textile Institute (2002) as "The quality of a fabric assessed by the reaction obtained from the sense of touch."

Fabric hand plays an important role regarding fabric drape behavior and tailoring performance in apparel manufacturing processes. In the apparel industry, it is of vital importance that manufacturers select an appropriate fabric for a specific apparel end use. Since textile industries are now able to produce a wide variety of apparel fabrics, finding a suitable fabric among different products had become more difficult for apparel manufacturers. On the other hand, textile and interior industries have increasingly been aware of the importance of fabric hand in consumer preferences and choice. Fabric end-use preference and selection criteria are largely based on fabric hand because it relates to both mechanical properties and the aesthetic appearance of clothing. In order to meet the needs and expectations of consumers, apparel industries have been using the technique of evaluation of fabric hand. However, most apparel manufacturers rely on subjective evaluation of fabric hand based on personal experience. This lacks a capability of precisely predicting fabric performance in the production process and actual wear.

In order to set up a standard method to define and test fabric hand quality, objective evaluation of fabric hand has become one of the most interesting studies in the textile field. Attempts to instrumentally evaluate the fabric hand have been made over the years. Instruments have been developed to test the fabric properties most relevant to fabric hand and numerical methods have been suggested to quantify fabric hand (to give a numeric value to fabric hand). The most comprehensive objective hand evaluation system is the Kawabata Evaluation System for Fabrics (KES-FB). This system was first developed in the 1980s and was focused on men's suiting fabrics. Fabric Assurance with Simple Testing (FAST) is another fabric hand testing system. Unlike the KES-FB, separate tests on fabric mechanical properties are not needed in the FAST system, though the mechanical parameters in the FAST system are highly in accordance with those in the KES-FB system. Both the KES-FB and FAST system uses precise instruments to measure fabric mechanical properties that determine fabric hand. However, because of the high cost for the instrument acquisition, maintenance, and technician training, fabric hand evaluation techniques and instruments have not been widely adopted by apparel manufacturers.

The Kawabata system uses multiple regression models to associate measured mechanical properties of fabrics with subjective preferences of hand experts. However, with better manufacturing conditions and technology, manufacturers are now capable of producing a larger variety of fabrics for consumers to choose. Because the quality of all kinds of fabrics varies greatly with fiber type and finishing methods, it is hard for manufacturers to retain hand grading expertise for their fabric products that is usually based on an assessment by their own fabric hand evaluator. Therefore, the need to develop a comprehensive objective evaluation system of fabric hand is imperative for the standardization of clothing production process control and quality prediction.

Among all kinds of textile and clothing products, men's suits and men's suiting fabrics are most quality-demanding, subject to the consumer preference for good handle and aesthetic appearance. High demand for high-quality men's suiting products for professional business occasions and hospitality services had become a major drive in the study of fabric hand evaluation. In association with the wool and wool-rich suiting fabric market, this study examines the technique of classification and hand grading of men's suiting fabrics by use of commercial suiting fabric products. A group of commercial men's suiting fabrics were tested and evaluated. This fabric sample collection represents a range of different suiting fabrics in terms of different fibers, fabric structures, and fabric finishes.

1.2 Background

1.2.1 Fabric Hand Evaluation

In the fabric hand evaluation, fabric mechanical properties are intimately related to fabric selection for designers and quality assurance for apparel manufacturers. Physical tests that analyze the fabric tactile properties require numerical measurements. In order to determine fabric tactile properties, related mechanical properties of fabrics can be selected to test using KES-FB and be applied to the fabric hand interpretation called the Kawabata's total hand value. In this study, statistical analysis and artificial neural networks are also used to analyze the obtained fabric data set and to establish fabric hand evaluation models.

More than 80 years has passed since Peirce (1930) first established a study in the field of objective evaluation of fabric hand by setting up equations for evaluating fabric mechanical properties including compression, frictional property, bending length, bending rigidity and modulus. The most insightful studies on the objective fabric hand evaluation were carried out by Kawabata (1980) and The Hand Evaluation and Standardization Committee (HESC) with detailed investigations on the tactile nature of fabric hand of men's winter suits. Their studies established the Kawabata instrument system (KES-FB) and provided an objective fabric hand ranking on a scale of 0 to 5 called the Total Hand Value (THV), with Rank 0 as unacceptable fabric hand and Rank 5 as excellent fabric hand. Kawabata et al. (1982) developed a stepwise linear regression model to create equations for predicting primary hand value (PHV) such as KOSHI, NUMERI and FUKURAMI.

Previous studies using objective hand evaluation technique were mainly focused on investigating how mechanical parameters of fabrics affect total hand value and analyzing peculiarities of hand value influenced by fiber content, fabric structure and finishing. Accompanying the studies of fabric objective hand evaluation, many instrumental devices such as the KES-FB instruments were developed and verified as simple and reliable devices to obtain quantitative information about fabric mechanical properties. However, few studies address the problem of how to classify fabrics and to grade fabric hand quality only according to fabric mechanical properties from an industrial point of view. Therefore, this study will focus on finding a practical way to incorporate the objective hand evaluation technology into the clothing manufacturing industry.

1.2.2 Suiting Fabrics

With the development of international trade and more frequent business activities, business attire is in big demand. Also, one of the highest labor populations, the hospitality industries, requires a large number of suiting and shirting apparel products. Finer suits worn by hotel employees can create a first-class professional image that helps to sell hotel brands. Therefore, fabric manufacturers are encouraged to produce a variety of luxury and high-end suiting fabrics to meet the need of discerning consumers.

The suiting application requires business suits and uniforms to drape well, to feel good when being touched and to maintain their form stability. Many suiting fabrics and apparel manufacturers aim to produce high-quality products with good hand, tailorabilty, drapability, and color fastness to match up the international standards. Manufacturers either develop their own standards or follow the general testing and processing standards set by professional organizations. However, objective hand evaluation system and devices have not been paid great attention to manufacturers because (1) the cost of testing devices and specialist training is high; (2) the hand evaluation and grading methods are not standardized; and (3) the equations and models used to calculate hand value are not based on the mechanical properties of manufacturers' own fabric products.

Because of the need for high-quality, exquisitely tailored men's suits in current fashion trends, apparel manufacturers are now using more knitted fabrics in suiting market. Knitted fabric has been applied to many men's suiting products to create a softer hand, better drape, and a more body-fitting appearance. For that reason, in addition to the regular wool-rich woven suiting fabrics, this research also studies knitted suiting fabrics and investigates the difference between woven and knitted suiting fabrics in their mechanical properties and hand grading. Considering the fact that clothing manufacturers have more varieties of suiting fabric to choose from, this study attempts to predict end uses of different kinds of suiting fabrics by setting up a classification model.

1.3 Research Objectives

This study addresses the need to better predict the hand qualities of men's suiting fabrics through instrumental measurements of the mechanical properties of commercial men's suiting fabrics. It focuses on evaluating instrumental methods for grading fabric hand and classifying men's suiting fabrics. Instrumental and statistical methods are used in the study to collect and analyze data representing mechanical properties of the commercial men's suiting fabric samples.

One major purpose of this study is to set up a model to classify men's suiting fabrics and to better understand fabric similarity and dissimilarity in terms of mechanical and physical properties. This further helps predict the fabric tailorability and apparel product quality. In the fabric classification model, new samples can be classified into existing fabric groups and be included into training data sets for dynamic model upgrade. By using this model, manufacturers are able to incorporate the features of their products into a customized database for fabric quality evaluation. Hence, such a fabric database helps manufacturers record the quality history of each fabric they produce, and enable the developing of dynamic models for the prediction of fabric hand grade, end, uses, and tailoribility.

Another purpose of this study is to perform an instrumental comparison of the grading of men's suiting fabric hand given by the Kawabata system and by a neural network model. Experiments were performed using the KES-FB devices and two types of hand value were calculated by the computing formulas given in the KES-FB system and by the neural network statistical model developed in this study.

Therefore, the study is divided into two major parts: (1) to classify and compare woven and knitted suiting fabrics according to their mechanical properties; (2) to validate the artificial neural network technique in grading fabric hand and to find its relationship to the hand value given by the Kawabata's total hand value.

Overall, the specific objectives of this study are:

1. Using the KES-FB devices to evaluate mechanical properties of a total of 95 commercial men's suiting fabrics including 65 woven fabrics and 30 knitted fabrics.

2. Classifying the men's suiting fabric samples with statistical tools such as cluster analysis based on their mechanical properties and total hand value given by Kawabata's equations.
3. Based on the classification results, evaluating fabric similarity and dissimilarity among the woven and knitted suiting fabrics collected in this study.
4. By using the neural network model and classification results, creating a hand index for grading suiting fabrics in contrast to the Kawabata's total hand value.
5. Examining the relationship between the hand values graded by Kawabata's methods and neural network technique.

Chapter 2 Literature Review

2.1 Introduction

To study the hand value evaluation and classification methods on men's suiting fabrics for commercial uniform uses, one needs to have a clear and comprehensive idea of the challenges in this field. This literature review of previous findings shows a general picture of the situation of the current suiting fabric market and objective hand evaluation techniques. This chapter aims to review the development in objective hand evaluation studies for engineered manufacturing and to find out what needs should be met in this research field.

This literature review includes three parts: the development of objective hand evaluation methods; the current suiting market; the neural network technique and its use in the textile technology field.

Because of the complexity of describing fabric hand, to find out comprehensive methods to quantify fabric hand has become one of the major challenges for textile researchers. Efforts have been made over a century to develop a standardized method to evaluate fabric hand. In the first part of this chapter, methods and processes employed to study fabric hand were summarized and analyzed. Then, in the second part, the current situation of men's suiting fabric was discussed and approaches made by researchers to investigate the engineered manufacturing technique were examined. Lastly, the neural network technique was introduced and several studies in the textile and apparel research field incorporating neural network techniques were reviewed.

2.2 Objective Fabric Hand Evaluation

In textile and apparel industries, fabric objective measurement of mechanical and surface properties is a powerful tool for many uses such as quality control, finishing operations, fabric classification and hand evaluation. Especially, the application of objective fabric hand evaluation is becoming essential as the level of automation in apparel manufacture is increased and the apparel industry lacks personnel with profound textile knowledge. An understanding of the mechanics of fabrics is of great importance to predict fabric hand and further, to give instruction to a series of manufacturing process such as sourcing and design, clothing construction, quality control and product development. Therefore, studies on objective hand evaluation have been continually and actively carried on in the last hundred years.

2.2.1 Fabric Hand Definition and Evaluation

In terms of finding a method for comfort and quality evaluation of textiles, "fabric hand" is a common concept. According to Textile Terms and Definitions, the definition of fabric hand refers to the quality of fabric assessed by touch perceiving process ("TEXTILE TERMS AND DEFINITIONS," 1962). Fabric hand is also defined as "the summation of weighted contribution of stimuli evoked by fabric on major sensory centers" (Gooch, 2011). The terms "fabric hand", "hand" or "handle" are used for describing such complex property of fabrics. Fabric hand is considered affected by many factors contributing to the difference on tactile sensory response. Because hand is a complex sensory property of a fabric subject to a complex deformation, these factors are often represented by different mechanical properties in quantitative research methods. Closely associated with fabric mechanical properties, hand has been defined as "a perceived overall fabric aesthetic quality that reflects the fabric mechanical and physical properties"(Kim & Slaten, 1999).

Methods to evaluate fabric hand include subjective and objective evaluation approaches. Ciesielska-Wrobel & Van Langenhove (2012) stated in their study that subjective hand evaluation is an analysis and presentation of the sensory evoked by fabrics using different tools such as interview and questionnaire. The subjective hand evaluation techniques usually directly describe fabric hand by using adjectives and terms (Ciesielska-Wrobel & Van Langenhove, 2012). For example, in the study of Philippe et al. (2004), descriptive analysis of fabric hand was used in order to analyze similarities and differences in perceived quality of fabrics. Terms used to describe fabric hand such as “Soft,” “Slippery,” “Crumple-like” and “Elastic” are used for subjectively describing fabric hand features (Philippe, Schacher, Adolphe, & Dacremont, 2004).

The other technique to evaluate fabric hand is objective hand evaluation using instruments to test certain mechanical properties of fabrics. Chosen mechanical parameters of fabrics are calculated and converted into a hand value to present fabric hand quality. By assigning numerical values to fabric hand, fabric hand can be presented as quantified outputs. Studies on objective hand evaluation has been developed over years with trials based on various types of fabrics such as woven (Hoffman & Beste, 1951; Kuo, Lin, & Su, 2011; Lam & Postle, 2007), nonwoven (Kawabata, Niwa, & Fumei, 1994), knitted fabrics (Choi & Ashdown, 2000; Gong, 1995; Mahar & Wang, 2010) and the effect of finishing treatments.

2.2.2 Development of Objective Fabric Hand Evaluation Methods

In the last hundred years, objective hand evaluation has been studied through integrated investigations of different testing methods and correlation between mechanical properties and subjective fabric hand grades.

Peirce (1930) first clearly stated the importance of research on fabric hand and mechanical properties for engineered manufacturing design. By employing instruments such as cantilever and hanging loop methods, the objective techniques for evaluating the fabric drape property were introduced. The study stated that it is preferable and possible to do physical tests on fabric and assign numerical values to fabric properties (Peirce, 1930). Since then, objective fabric hand evaluation has become one of the major research interests in the textile technology field.

In 1970, Kawabata and Niwa established a research committee called the Hand Evaluation and Standardization Committee in Japan and started their study on how to quantify fabric hand. The research was carried out by evaluating men's suiting fabrics by textile experts from textile mills and by developing the KES-FB instruments for fabric mechanical property measurement. They correlated the subjective fabric hand evaluation with mechanical property measurement to establish a set of empirical equations for fabric hand calculation. The nonlinear fabric properties are quantified and used to calculate the hand value using weighting system (Raheel, 1996).

The KES system is a set of four instruments used to measure sixteen characteristics of different textile material. It measures: mechanical properties including tensile, bending, shear and compression; surface properties of friction and roughness; and construction characteristic of thickness, as shown in Table 2.1. The instruments are able to provide numerical values representing mechanical properties that can be used to determine fabric hand performance. The description of the mechanical properties is shown in Table 2.2. Then, the analysis of fabric hand was divided into two steps. The first step is the evaluation of fabric hand to describe specific fabric characteristics using three hand expressions called "primary hand (HV)." The three hand expressions are KOSHI (stiffness), NUMERI (smoothness), and FUKURAMI (fullness). Different hand expressions are employed depending on fabric end uses, as shown in Table 2.3. The second step is to convert HV into the overall hand value called "total hand value (THV)" which indicates the overall performance of the fabric in apparel use. THV have a value range from 1 to 5 grading fabric hand performance from the worst to the best, as shown in Table 2.5.

In this Japanese method, the subjective presentation of fabric hand was translated into objective hand evaluation based on the mechanical properties of fabrics. It becomes possible to describe fabric hand using numerical variables. In the process of developing the objective evaluation system, they first focused on men's suiting fabric and accordingly introduced different equations to calculate fabric hand value based on specific type of men's suiting such as winter suits and summer suits. As more studies have been carried on in this area, the concept of KES has been applied to other fabrics such as ladies' garment fabrics, outerwear fabrics, and nonwovens. For example, researchers found that the equations previously developed for men's suiting are applicable to predict the hand of nonwovens with a slight difference between the criteria of the quality (Kawabata et al., 1994). The KES system has been successfully applied to meaningful studies on objective analysis of many kinds of apparel fabrics. The major advantage of using the KES in textile technology field is to provide appropriate and sufficient information of fabrics for apparel designers, fabric and apparel quality control technologists, and retail customer service specialists.

Table 2.1 Fabric mechanical blocks from the KES-FB measurements

Block number	Property	Mechanical parameter
B1	Tensile	LT, WT, RT, EMT
B2	Bending	B, 2HB
B3	Shear	G, 2HG, 2HG5
B4	Compression	LC, WC, RC
B5	Surface Properties	MIU, MMD, SMD
B6	Weight and thickness	W, T

Table 2.2 KES-FB mechanical parameters

Property	Mechanical	Description
Tensile	EMT	Elongation (%)
	LT	Linearity of load-extension curve
	WT	Tensile energy (gf·cm/cm^2)
	RT	Tensile resilience (%)
Bending	B	Bending rigidity (gf/cm·degree)
	2HB	Hysteresis of bending moment (gf·cm/cm)
Shear	G	Shear rigidity (gf/cm·degree)
	2HG	Hysteresis of shear force at 0.5 degrees of shear angle (gf/cm)
	2HG5	Hysteresis of shear force at 5 degrees of shear angle (gf/cm)
Compression	LC	Linearity of compression-thickness curve (ND)
	WC	Compression energy (gf·cm/cm^2)
	RC	Compression resilience (%)
Surface	MIU	Coefficient of friction (ND)
	MMD	Mean deviation of MIU (ND)
	SMD	Geometrical roughness (μm)
Fabric Construction	W	Fabric weight per unit area (mg/cm^2)
	T	Fabric thickness (cm)

Table 2.3 Kawabata's expression of primary hand (HV)

Winter/Autumn suiting	Summer suiting
KOSHI (Stiffness)	KOSHI (Stiffness)
NUMERI (Smoothness)	SHARI (Crispness)
FUKURAMI (Fullness)	FUKURAMI (Fullness)
	HARI (Anti-drape)

Table 2.4 Grading of primary hand

Primary hand value (HV)	Grade of feeling
10	Strongest
9	Very strong
...	...
5	Average
...	...
1	Very weak
0	No feeling

Table 2.5 Total hand value (THV)

Total hand value	Grading of hand
5	Excellent
4	Good
3	Average
2	Fair
1	Poor

Although the Kawabata system provided the first commercially available instruments for apparel fabric hand evaluation, its complicated test procedure and cost were major barriers to end users. The Commonwealth Scientific and Industrial Research Organization (CSIRO) developed the Fabric Assurance by Simple Testing (FAST) system. It was designed and promoted to predict the properties of wool and wool-blend fabrics in the first place (Stylios, 2005). Therefore, like KES, the FAST system gives information related to fabric handle. But unlike KES, the FAST system only measures the resistance of fabric to deformation, and does not measure the fabric recovery.

Similarly, KES and Fast applications, both measure the response of fabrics to low stress deformation similar to actual wear. They play an important role in the development of studies on objective hand evaluation as they provide sufficient information for researchers to improve fabric hand, drape and tailorability (Matthews,1985). However, there are some limitations to the use of KES or FAST measurements in predicting fabric hand for industrial practice. First, since the mechanical measurements are complicated, experienced technicians are needed to analyze and interpret the relationship between the fabric mechanical properties and fabric hand implied in the data. Second, because some of the parameters may be highly correlated, the actual relationship between mechanical parameters and fabric hand may not be simple linear one. Third, because that both KESF and FAST are designed for woven fabrics, the practicability of using these instruments to test other types of fabric such as highly extensive knitted fabrics needs further examination and validation.

A simple approach to evaluating knitted fabric hand used the pulling method, also referred to as the ring test, was introduced to complement the study on handle of next-to skin wear fabrics. The pulling method examined the deformation properties of fabrics measuring the force needed for them to be pulled through a ring or nozzle (Kim & Slaten, 1999; P. Zhang, Liu, Wang, & Wang, 2006).

Similar to the ring test, Strazdienė, Martišitė, Gutauskas, & Papreckienė (2003) introduced a new method for textile objective evaluation using instruments to examine the geometrical deformation of knitted fabrics when they are pulled. The researchers studied the value of pulling force, pulling distance and the geometry of the pulling curve when fabrics are stretched to illustrate the process of bending, draping and jamming. This pulling method was considered useful in this study to predict textile hand and evaluate other properties of textile materials such as drapability (Strazdienė, Martišitė, Gutauskas, & Papreckienė, 2003). However, a limitation of this method is that the deformation is two-dimensional and therefore is unable to give a comprehensive description of fabric mechanical properties. The mechanical properties that affect fabric handle are intimately related not only to drape but also to other attributes such as crease resistance, surface smoothness and compression.

Furthermore, based on the previous research on the ring test, Nu Cybertek, Inc. from the USA developed the PhabrOmeter with automatic processing procedure. The PhabrOmeter analyzes and quantifies new parameters such as “relative hand value”, “drape index” and “wrinkle recovery rate” (Pan, 2007). Because of its convenience, it has been used in many applications (Mahar & Wang, 2010).

In general, researchers in this area have tried to introduce and examine many objective evaluation instruments and methods over the years. Applications of developed fabric hand evaluation systems such KESF and FAST concentrate mostly on the use of measurements and hand value for research, instead of industrial practice such as a fabric quality control tool or end use prediction model. Though these techniques have been used for objective hand evaluation, few manufacturers actually employ the objective hand evaluation instruments and techniques such as KES and FAST because of substantially high cost to acquire the devices and to train their own specialists to operate these systems and interpret the test results (Bacci et al., 2012). Interpretation of data retrieved from the hand evaluation instruments requires comprehensive understanding of fabric property mechanism and experience in apparel manufacturing processes. Also, the relationship between fabric properties and hand performance is still not clear. Therefore, the objective hand evaluation method becomes essential for manufacturers to characterize the hand (Bacci et al., 2012).

2.3 Assessment of Suiting Fabric Hand

2.3.1 Suiting Fabric Market

With the development of international markets and more frequent business activities, the demand for business suits is inevitably growing. In developing countries, the hotel industry is booming with an increasing demand for hotel uniforms. Large and high-end hotels such as Hilton Worldwide are able to afford high quality uniforms and professional uniform maintenance systems. Finer suits worn by employees can create a first-class, professional image that helps to sell their brand.

Apparel manufacturers pay more attention to the men's suiting market. In order to raise men's self-esteem when entering the workplace, the MenzFit program launched in Philadelphia in 2008 had made efforts in making men look more professional. They emphasized the importance of professional men's suiting by stating that men walk with more confidence when they are dressed as regal as they can be (Booker, 2008).

In a market survey examining consumers' preference among different fabrics including wool, cotton and synthetic fabrics regarding luxury perceiving, the fact that wool is greatly related to luxury was revealed (Mahar & Wang, 2010). People associate wool with attributes of "symbol of status," "expensive" and "luxury" (Mahar & Wang, 2010). The strong preference for choosing wool as an apparel fabric has a long historical standing in many countries.

Modern suits are mostly made of wool and wool-blend fabrics because of wool's versatility and comfort. Desirable traits of wool fabrics include resilience and draping properties, excellent dyeing properties, good resistance to heat and flame, resistance to soiling and moisture absorbance. Recent technical developments have enhanced the ability of wool fabrics to hold a crease and remain its original shape. Moreover, wool is frequently blended with other natural and synthetic fibers to meet different needs and preferences for performance enhancement and price cut-down.

Wool and wool-rich fabrics are able to provide many desirable characteristics such as good handle, rich luster, high moisture absorbency and hairy surface. Apart from the visual characteristics, the preference for a specific fabric is largely affected by hand. The hand of wool fabrics depends on many factors, such as fabric construction method, compressibility, elastic resilience and recovery (Hopkins, 1950). These affecting factors are later synthesized and summarized into fabric parameters that can be measured.

Wool is an important fiber in the apparel industry with retail sales of nearly $75 billion a year (Millward Brown Pty Ltd, 2007). Australian apparel wool accounts for approximately 70% of the global use of apparel wool and the retail price is around $230 per kilogram (Swan, 2010). In the United States, leading wool producing states are Texas, Wyoming, California, Montana, Colorado, South Dakota, Utah and New Mexico. Four states including Texas, California, Wyoming and New Mexico contribute 81.5% of all high price fine wool produced in the U.S. The wool imported for U.S. grown wool apparel use go to central markets sharing the same large number of manufacturers (Leung, 2013).

However, the actual market price for suiting fabrics varies greatly. High-end brands produce fashion products in low quantity to keep their items exclusive and expensive. Sometimes, they design their own fabrics with new compositions. Original design requires more R&D resources leading to higher cost. Low-end brands tend to use lower-quality suiting materials by increasing synthetic fiber blend proportion to cut down the cost (Leung, 2013).

With the growing demand for finer and high-quality men's suiting, the capability of producing light-weight, soft, next-to skin suiting material products with low cost has become one of the major goals for apparel manufacturers.

2.3.2 Objective Hand Evaluation on Suiting Fabrics

Because of the high standard of suiting fabric quality and the indisputable potential of market demand, suiting fabric has become one of the major research interests in the apparel and textile field of study. Studies on objective hand evaluation of suiting fabric have been carried on from various aspects using different techniques.

In a study of Postle & Dhingra (1989), 200 suiting materials were studied to investigate a non-linear technique to optimize fabric quality. The researchers clearly stated that reliable objective measurement of mechanical and surface properties is the key link in the procedure to find an optimal solution for fabrics designed for a specific end-use (Postle & Dhingra, 1989). In their study, the best range of measurements of fabric mechanical properties were given to optimize the overall hand value for high-quality men's suiting. In order to achieve best hand for medium/heavy men's winter suiting fabrics, tensile extensibility EMT should be enhanced and bending rigidity B, shear hysteresis 2HG5, surface coefficient of friction MIU should be minimized. In comparison, the results showed that hand values for heavy suiting materials were generally higher than summer suiting.

Studies on suiting fabric hand evaluation give valuable information to predicting suiting fabrics performance in production such as tailorability and processability. In Behery's (1986) research, for example, physical properties relating to suiting fabric hand were evaluated and the tailorability of summer and winter suiting fabrics from the US and Japan were compared(Behery, 1986).

Some researchers investigated different approaches to create equations to calculate hand value based on researchers' own fabric samples. Sular and Okur (2008) investigated a new method to calculate total hand value using wool and wool blend samples collected from worsted fabric manufacturers. In this study, objective and subjective evaluation were combined to predict fabric handle with a minimum number of fabric parameter. Instead of using KES, researchers tested 71 fabric samples on simple laboratory instruments. Then, based on the results from subjective preference tests, researchers developed their own regression models using subjective value as the dependent variable. Similar to Kawabata's evaluations, a two-stage prediction procedure was suggested. The first stage was to calculate a total hand value called THV_{SC} based on subjective evaluation results describing primary handle characteristic (Sular & Okur, 2008). In the second stage, THV_{SC} calculated in the first stage served as a dependent variable to predict total hand value from objective measurements, THV_{OBJ}. However, the high correlation coefficients and consistency between subjective and objective evaluation results might have been due to the calculation method. Because of the calculation method, limited fabric parameters involved and the lack of agreement of standards the simple instruments follow, the predicted fabric hand determined by the model discussed in this article may not be practical fabric hand indicator.

As more knitted fabrics are used in men's suiting application, research on knitted fabric hand evaluation is gaining a weight in the effective fabric objective assessment for a wider range of suiting fabrics. Knitted fabrics have substantial different behaviors from that of woven fabrics in terms of fabric mechanical properties and handle. The instrumental measurements are even different between warp knits and weft knits. For instance, weft knits generally have higher flexibility with lower value of elastic rigidity B for bending (Skelton and Schoppee, 1976).

Gong (1995) investigated the practicability of hand measurement technique for quality control of knitted apparel fabrics. In this study, the objective evaluation on knitted fabric hand was done using KES-FB. This research found that shear stiffness and bending stiffness were two major properties that affected the resistance to loop deformation of knits. Also, the researcher commented that in order to achieve a comprehensive description of fabric hand, more work with a larger sample size needs to be done. For quality control on a routine basis in factories, a simpler, non-destructive and cheaper technique is needed (Gong, 1995).

Later in 2000, Choi and Ashdown (2000) studied the mechanical properties of weft knits in outerwear use. With the understanding of current market needs for finer, softer and higher-quality outerwear or suits, they especially focused on examining how knit structure and density could affect the performance of weft knitted fabrics for outerwear. Based on the test results implemented on KES-FB, they found that shear strain, rigidity and stress were largely affected by knitted fabric density. Tensile strength is generally proportional to the density of knitted fabrics that are not able to absorb much of external stress, especially in the course direction. Also, with higher knitted fabric density, surface smoothness increases greatly but varies little with different knitted structures. What is more, the eighteen weft knitted fabrics tested in the study generally have good total hand value (THV) ranging from 2.87 to 4.57. THV rose as the knitted fabric density increased (Choi & Ashdown, 2000). Generally, the measurements of fabric mechanics and the results of hand evaluation on weft knitted fabrics are very different from those of woven fabrics in other studies.

While the above study has provided valuable information regarding the hand value of weft knitted fabrics for outerwear, such narrow focus may not apply to all knitted suiting fabrics for quality assurance in apparel manufacturing. It may therefore be advantageous to also involve warp knits as well as weft knits in the studies of fabric hand evaluation. For that reason, both weft knitted and warp knitted fabrics for suiting wear are tested for hand evaluation in this thesis.

Except for the research discussed above, other approaches to evaluate suiting fabric hand are employed in many research projects using new techniques. In 2000, Chen et al. used mechanical properties measured by the KES-FB instruments and then introduced fuzzy evaluation to grade fabric softness (insert reference). This study established a fuzzy model to describe fabric softness and applied it to fabric softness grading. In this study, the fullness and softness of cotton woven fabrics for fuzzy grading were evaluated and the correlation between the fuzzy grade and subjective grade was examined. The research found that the relationship between fuzzy grade and subjective grade is close and consistent for different cotton fabrics. To address the problem of large variety of fabrics, statistical methods such as variance analysis and factor analysis were used to determine weighting factor in the fuzzy matrix.

Because most of the previous research on suiting fabric hand studied woven fabrics, the researchers in this study emphasized the need for systematic studies of mechanical properties and hand of various fabrics in order to meet the need of greater efficiency in apparel manufacturing.

2.4 Neural Network

Artificial Neural Networks (ANNs) are techniques attempting to mimic the capability of human brains to learn and response (Chattopadhyay & Guha, 2004). As shown in Figure 2.1, they consist of three parts (input; hidden layer and output) and the most basic element is called neuron. Each neuron receives inputs from other neurons in other layers and then outputs as results. Neural networks are capable of creating layers and developing adaptive weights to connect these layers based on learning results from the inputs. The network function is affected greatly by the inter-connections between neurons, some of which are based on non-linear relationships (Z. Zhang & Friedrich, 2003). In ANN methods, a dataset is usually divided into two parts: training dataset and test dataset. The training dataset is used to give the weights of neurons and then the ANN model performance is evaluated by testing the test dataset (Bose, 2000).

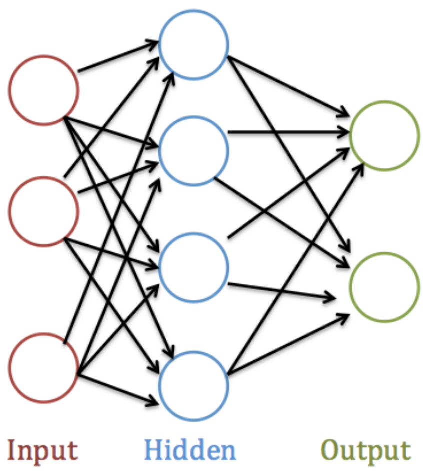

Figure 2.1 Artificial Neural Network layers

ANNs have been used in many studies in textile and clothing industries such as fiber classification, defect classification (Habib & Rokonuzzaman, 2012), fabric property prediction (Behera & Mishra, 2007; Hadizadeh, Jeddi, & Tehran, 2009; Jiang, Zhang, & Friedrich, 2007), fabric end-use prediction (Chen, Zhao, & Collier, 2001) and fabric hand prediction (Hui, Lau, Ng, & Chan, 2004).

2.4.1 Fabric Property Prediction

Shin-Woong et al., (2001) investigated total handle of knitted fabrics using neural network theories and compared the results to subjective tests. In the study, Shin-Woong et al. tested 47 commercial weft knitted and warp knitted samples using KES-FB system and seven mechanical properties were selected for fuzzifying into a value within 0 and 1 indicating a fuzzy hand value. In this study, the researchers used two theories (fuzzy and neural networks) for the objective evaluation. The results of subjective evaluation from 30 judges were used as output in ANN system to construct a neural network approach. Also, a subjective evaluation was carried out in order to compare the result from the fuzzy and neural network method. This approach clearly gave an example of evaluating the hand of knitted fabrics using ANNs with Kawabata's measurements as input and subjective values as desired output. However, the end-uses of these samples vary from summer to winter clothing. The study focused on generally validating and comparing the hand value results programmed by ANNs. However, it did not point out potential application of this method.

Behera and Mishra (2007) studied the relations of functional and aesthetic properties of worsted suiting fabrics using ANNs. A total of 58 worsted suiting fabric samples were tested using KES, FAST and an image processing-based system regarding their constructional and aesthetic properties. The researchers especially examined the prediction of worsted suiting fabric properties from fiber parameters as input in the ANNs model. The larger wool blend ratio in fiber content led to a better appearance and higher total hand value in winter application. This was because increasing the wool fiber blend ratio added smoothness and fullness to the fabrics (Behera & Mishra, 2007). However, this was not the case for summer suiting application as fullness had an adverse effect on the requirement of a crisp feel for summer application. By comparing the prediction results for fabrics of winter and summer application, one must admit the variety of suiting fabrics and the need to develop a proper way of choosing the appropriate end-use for suiting fabrics based on their mechanical properties. In this study, commercial suiting fabrics mostly consist of wool and wool blend such as wool/nylon, wool/PET and acrylic blends. Though the fabric sample composition used in that study was very similar to that used in this thesis, the samples tested in this thesis are mainly considered for winter suiting use. Also, the suiting fabric finishes should have been considered to join the parameter set as input since the suiting fabric performance is greatly affected by finishing parameters (Behera & Mishra, 2007).

2.4.2 Fabric End-Use Prediction

Fabric end-use prediction is another major application of ANN technique in textile and apparel technology. Establishing a relationship between fabric mechanical properties and different end uses helps designers and manufacturers to better incorporate fabric features into apparel products so that the appropriate use of textile materials can be obtained.

In the study of Chen et al., (2001), instrumental parameters of 100 apparel fabric samples retrieved from KES-FB were collected for training data. First, the 100 apparel fabric samples were divided into three groups (blouses, shirts, and suiting) as desired input. Then, in the neural network computation process, 90 samples were used as a training data set and 10 were used as the testing data set. The output shows values between 0 and 1 indicating which category each tested sample belongs to. In this model using ANNs, relationships between fabric parameters and fabric end uses were set up. The prediction error rate of the model was evaluated by using a cross-validation method. This technique of incorporating ANNs with Kawabata's objective evaluation can help solve the problem of scarcity of experienced fabric specialists for new fabric sourcing and fabric end-use prediction in manufacture (Chen et al., 2001). In order to enhance manufacturing efficiency this area of study should be continued with more investigation.

Later in the study of Shyr, Lai and Lin (2004), a new approach using ANNs and stepwise regression model to establish a total hand equation was introduced. Though the mechanical properties are based on KES measurements, the primary hand value transformation was not needed in this model. After examining the correlation between 16 parameters in Kawabata's measurement, four relatively independent fabric parameters (LC, 2HG, B and WT) were selected and used as inputs in the ANNs configuration. The approach was identified as an effective method to develop translation equations for different fabrics in the textile industry (Shyr, Lai, & Lin, 2004). However, because of the limited number of fabric parameters selected as inputs in the ANN model, there is less inter-connection between the neurons in each layer of the ANN model. Therefore, the output calculated from the limited weighted inputs may not be able to comprehensively predict fabric hand.

In order to enhance the performance of ANN models, some issues should be considered including choosing adequate model inputs, model of data processing, training stopping criteria and model validation method. However, the biggest challenges of using ANNs evaluating fabric hand are the lack of a large dataset of different kinds of fabric and the criteria to choose appropriate parameters for the inputs. Possibly in the future, textile and apparel manufacturers will be able to apply the ANNs technology in fabric property prediction using their own databases. The significance of using ANNs in fabric end-use prediction for industrial applications will be discussed in the conclusion chapter in this thesis.

Chapter 3 Methodology

In this study, 95 samples of men's suiting fabrics collected from fabric manufacturers were tested in terms of mechanical properties using the Kawabata Evaluation System. The test results were used to calculate the suiting fabric total hand value (THV) and to classify the fabric samples for further evaluation. This chapter describes the research experiment design and methodology, including sampling, instruments, testing procedures and statistical tools used for the established data set.

The research objectives in this study include: 1) Analysis and comparison of the fabric mechanical properties and Kawabata's hand value of woven and knitted suiting fabric samples, 2) classification of the men's suiting fabric samples using cluster analysis based on their mechanical properties collected from KES-FB, 3) evaluation of the similarities and dissimilarities of fabric properties between woven and knitted fabrics, 4) creation of a hand property indicator called hand index using results from cluster analysis and classification techniques, 5) examination of the relationship between the hand value graded by the Kawabata's empirical equations and the hand index computed by the neural network model.

The purposes of this chapter are (1) to introduce the research experiment and goals of this study; (2) to provide information about the samples tested; (3) to describe the instruments and procedures of fabric property testing and data collecting; and (4) to explain the statistical procedures used to analyze the obtained data.

3.1 Research Design

To address the research questions mentioned in the previous chapters, this study has two major aims. The first one is to set up a model to classify men's suiting fabrics employing the fabric mechanical properties, so as to better understand characteristics of each classified subset related to physical attributes and fabric hand quality. The second aim is to compare the hand value grading result given by THV and Neural Network and examine the relationship between these two methods. To achieve this, the research approach was designed into two main steps: experiment and data analysis.

The experiment was conducted by the measurement of fabric mechanical properties with the instruments of Kawabata Evaluation System for Fabrics (KES-FB). The measured data was collected to form a training data set for the fabric classification and neural network analysis. The KES-FB instruments consist of 16 instrumental parameters that provide 16 variables for the suiting fabric samples for objective hand evaluation and other statistical analysis.

In the data analysis part, the raw data was analyzed, visualized, and summarized using different statistical tools in the Statistical Analysis System (SAS) program. The data analysis using SAS included data distribution, cluster analysis, discriminant analysis, and correlation coefficient analysis. Furthermore, artificial neural network (ANN) was employed to produce a computational model of grading men's suiting fabric hand.

3.2 Experiments

3.2.1 Fabric Samples

A total of 95 fabric samples were evaluated in this study, including 65 woven samples and 30 knitted samples. These samples are commercial products from Chinese manufacturers and are commonly used as suiting fabrics. As shown in Table 3.1, the 65 woven fabric samples have diversified fiber composition including wool, silk, polyester, Tencel®, and elastic fiber. Among the 30 knitted fabric samples, 13 of them are filling knits and 17 are warp knits and they differ in knitting structure. All the fabrics tested in the experiment are assumed to be appropriate for men's winter suiting fabrics.

Test specimens of the suiting fabric samples were cut in size of 20 cm × 20 cm and were conditioned in standard testing condition (20±2 ^{0}C, (65±3% RH) for at least 24 hours before testing. Each fabric sample was tested in both warp and filling directions.

Table 3.1 Woven fabric samples

Fiber Content	Number of Samples
100% Wool (W)	22
Wool/Elastic (WE)	4
Wool/Polyester (WP)	10
Wool/Polyester/ Elastic (WPE)	7
Wool/Polyester/Sorona® (WPSO)	9
Wool/Polyester/Tencel® (WPT)	1
Wool/Polyester/Viscose (WPV)	1
Wool/Polyester/PTT (WPPT)	1
Wool/Polyester/Silk/Elastic (WPSE)	3
Wool/Nylon (WN)	2
Wool/Silk (WS)	3
Other wool blended	2
Total	65

3.2.2 Testing Procedure

A set of 95 suiting fabrics was tested using the KES-FB instruments for the evaluation of fabric mechanical properties. As shown in Table 3.2, the basic mechanical properties of extension, shear, bending, compression, surface friction and surface roughness are listed. For each fabric sample, a total of 16 mechanical parameters were tested with 3 replicates, and were averaged to calculate its total hand value (THV).

Table 3.2 Characteristic values of basic mechanical properties

Properties	Parameter	Description
Tensile	EMT	Elongation (%)
	LT	Linearity of load-extension curve
	WT	Tensile energy (gf·cm/cm^2)
	RT	Resilience (%)
Bending	B	Bending rigidity (gf·cm^2/cm)
	2HB	Histeresis (gf·cm^2/cm)
Shear	G	Shear stiffness (gf/cm·degree)
	2HG	Histeresis at 0.5^0
	2HG5	Histeresis at 5^0
Compression	LC	Linearity
	WC	Compressional energy
	RC	Resilience
Surface	MIU	Coefficient of friction
	MMD	Mean Deviation of MIU
	SMD	Geometrical Roughness
Thickness	T	Weight per area (g/ m^2)
Weight	W	Thickness at 0.5 gf/cm^2

The KES-FB system consists of four instruments, KES-FB1, KES-FB2, KES-FB3 and KES-FB4, for testing different mechanical properties, as shown in Table 3.3. Each of these instruments is connected to a computer that runs the LabView software program to record, calculate, and output test results correspond to the respective fabric properties. The testing instruments and control units are shown in Figure 3.1 – 3.5. Examples of test curves are given in Figure 3.6 -3.9.

Table 3.3 KES-FB System

Machine Block	Fabric Properties	Parameters measured
KES-FB1	Tensile and Shear	LT, WT, RT, G, 2HG, 2HG5
KES-FB2	Pure bending	B, 2HB
KES-FB3	Compression	LC, WC, RC, T
KES-FB4	Surface	MIU, MMD, SMD

Sample handling and mounting is manually operated and the device needs to be calibrated before each measurement. Instrument setting and adjustment relies on fabric types and mechanical properties. In this study, some special adjustments were performed for some knitted fabric samples with substantial larger extensibility.

Figure 3.1 KES-FB Tensile and Shear Tester

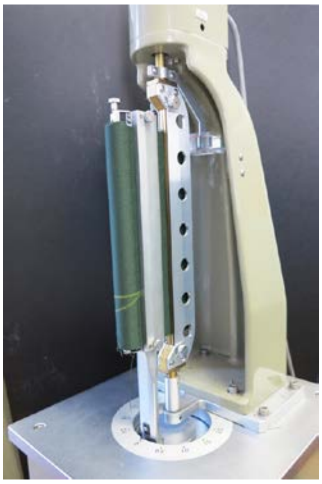

Figure 3.2 KES-FB2 Pure Bending Tester

Figure 3.3 KES-FB3 Compression Tester

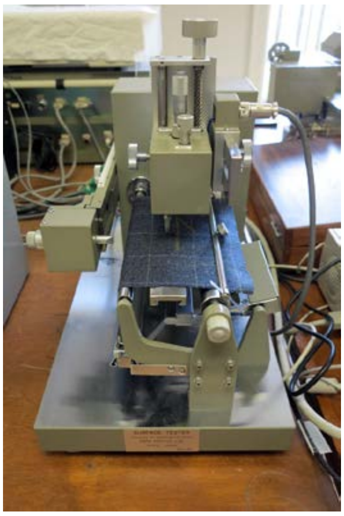

Figure 3.4 KES-FB4 Surface Friction and Roughness Tester

Figure 3.5 Instrument Electronic Control Unit

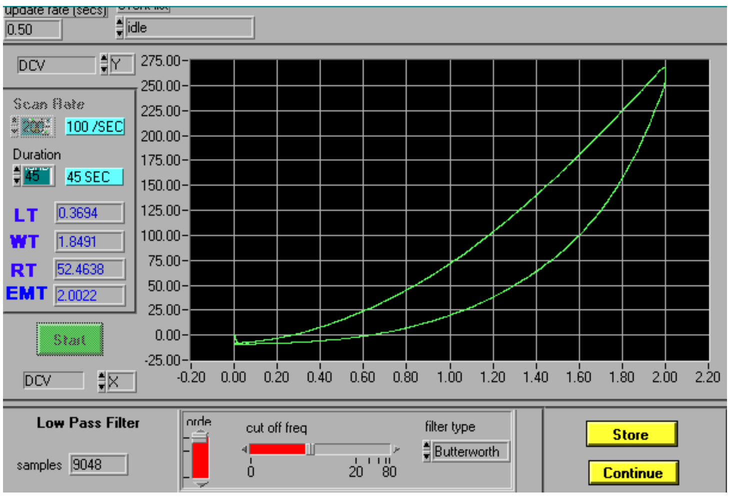

Figure 3. 6 Tensile test Curve

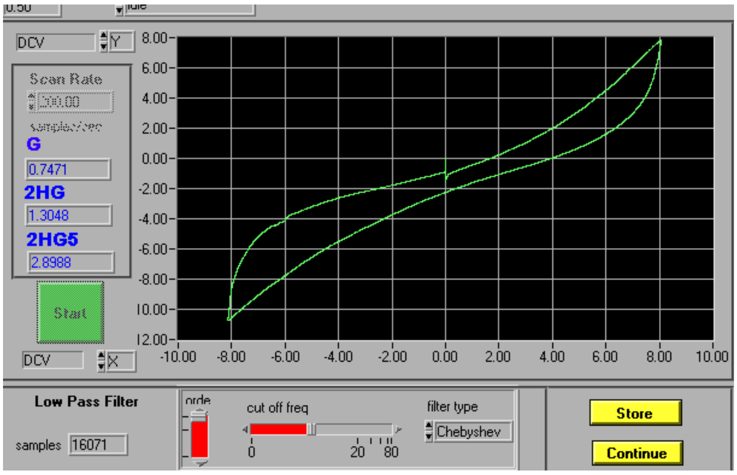

Figure 3.7 Pure shear test Curve

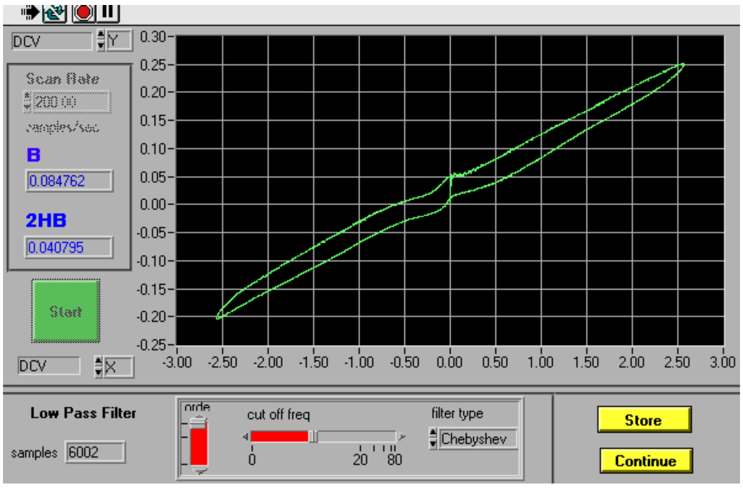

Figure 3.8 Bending test curve

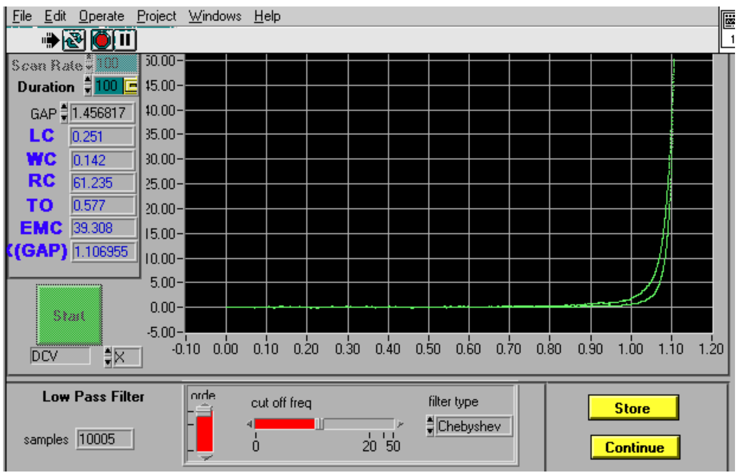

Figure 3.9 Compression test Curve

The 16 mechanical parameters related to the hand evaluation were proposed to predict fabric handle (Kawabata, 1982). These parameters were used in the equations KN-101-WINTER to calculate the hand value of men's winter suiting fabrics. The set of equations KN-101-WINTER was established by a multiple regression technique based on the instrumental data from the Kawabata Evaluation System and subjective input of hand evaluation from suiting fabric experts.

$$Y = C_0 + \sum_{t=1}^{16} C_i \frac{X_i - \overline{X_\iota}}{\delta i} \qquad (3.1)$$

Y; hand value

X_i; the i th characteristic value

$\overline{X_\iota}$ and δi; the mean value and the standard deviation of the i th characteristic value

C_0 and C_i; parameters (constant coefficient). See Appendix-D for men's winter suiting fabric coefficients

For example, in case of KOSHI of men's winter suiting fabric, the KN-101-WINTER-KOSHI is applied with the different coefficients C_0 and C_i. From Appendix-D, the equation can be written up as follows. The table of the constant coefficient in this equation can be found in Appendix-D.

$$Y = 5.7093 + 0.8459 \frac{logB - (-1.0084)}{0.1267} - 0.2104 \frac{log2HB - (-1.3476)}{0.1801} + \cdots \quad (3.2)$$

According to the Kawabata hand equations, the grade of hand evaluation is expressed as Total Hand Value (THV), as it is shown in Table 3.3. THV is from a linear combination of fabric primary hand value, bringing a concept of overall fabric quality relating to appearance, comfort and formability. First, the measurement of fabric basic mechanical properties is performed and the instrumental data is put into an equation to calculate fabric hand value, called Primary Hand Value (HV). The primary hand value has a grade range from 0 to

10 as shown in Table 2.4. Then, HV is used to calculate the Total Hand Value (THV) that has a grade range from 0 to 5 (Table 2.5). HV indicates the validity to characterizing fabric handle and THV represents a grade of the overall fabric hand quality.

In this study, THV is calculated for a purpose of comparison of the fabric hand among the collected suiting fabric samples. It is also used to compare with the fabric hand grading results from neural network models.

3.3 Statistical Tools

One of the objects of this study is to examine a feasible and logical classification method of men's suiting fabrics through a rational mathematical process. Cluster analysis and discriminant analysis were computed using the instrumental data obtained from the KES-FB system to sort the suiting fabric samples.

The other goal of the study is finding out the relationship between the fabric hand value indicated by THV and neural network output. Before using the neural network to predict the hand ranking based on the fabric mechanical properties, a criterion of grading the men's suiting fabrics should be established. Then, a neural network model needs to be selected to train the fabric data set. The fabric samples were sorted into groups according to their significant attributes from cluster analysis output. After the completion of the neural network computation, Pearson's correlation coefficients were used to measure the strength and direction of the linear relationship between total hand value and neural network output. Also, regression analysis was computed to help examine the correlation between neural network outputs and THV.

3.3.1 Cluster Analysis

Cluster Analysis is used in this study to classify fabric samples into groups without end-use assumptions. Since there is no prior information about the group membership for any of these fabric samples, the result can help interpret the fabric features. The cluster method used in this study is the non-hierarchical method, often referred as K means clustering. However, the k-means clustering does not give an optimal number of clusters. The clusters are homogenous and the differences among various groups are as large as possible. Therefore, the clustering can be helpful for apparel manufacturers to determine the fabric quality control range and to predict fabric end uses.

After classifying the fabric samples into different groups, the mechanical properties and THV of the fabric samples in the groups are described and compared. The discussion based on the result of cluster analysis gives directions for assessing the appropriateness of using these samples for suiting apparel production.

3.3.2 Discriminant Analysis

In this study, linear discriminant analysis is used to validate the cluster groups resulted from the K-means method. In discriminant analysis, the model of classification is set according to the cluster analysis output. Therefore, the effectiveness of the KES-FB data set in predicting category membership and significance of separating the clusters can be further examined. The develop discriminant functions are also used to graphically interpret the clustering result.

3.3.3 Artificial Neural Network

Artificial Neural Network (ANN) is a set of computational machine learning methods, often used in computer science and related fields. Artificial neural networks are nonlinear learning machines adapted from processing elements (PEs). The most common neural network model is the multilayer perceptron (MLP). As shown in Fig.6, PEs can form a layered structure and each PE is connected with inputs or other PEs using different discriminant functions. These functions are controlled by the network weights that can be adjusted and adapted according to the training dataset without statistical assumptions. Therefore, the neural network system is able to systematically classify the samples as accurately as possible using a training algorithm. The error is acquired by comparing the output with a desired outcome and then the system modifies the weight put on different functions. (I.A Basheer and M Hajmeer, 2000)

As a computing technique, ANN has been introduced to predict fabric end uses in previous studies. In this study, the fabric samples are divided into two parts: the training data set and the testing data set. The training data set provides a criterion of good hand value for men's suiting fabric end use. Then the software learns from the training data set and the model is created using the training data to produce the output. The neural network software, NeuroSolutions for Excel, was used in this study for the ANN evaluation. The interface of the software is shown in Figure 3.6. 65 suiting fabric samples were selected as the training dataset, including 30 representing the best hand quality and 35 representing the worst. The training dataset is selected from fabric samples considered to be appropriate for men's suiting. The fabric samples in the training dataset to represent best hand and worst hand are selected according to their THV.

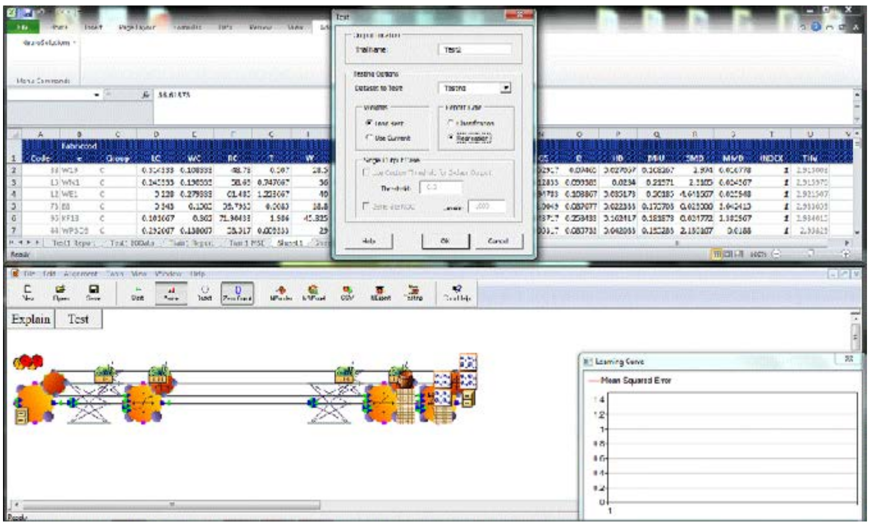

Figure 3.10 NeuroSolutions Interface

3.3.4 Correlation Coefficient

In order to examine the feasibility and effectiveness of grading fabric hand using neural network, this study intends to find out if the correlation between ANNs and THV reflects a linear or curvilinear relationship. The ranking of fabric hand given by ANN is compared with THV. The relationship between these two ranking method is examined by the correlation coefficient method. The association between fabric mechanical properties and end-use prediction helps to combine objective evaluation with industry experience in fabric selection and garment production (Chen et al., 2001).

To investigate the relationship between the fabric hand grades given by THV and neural network output, Pearson's correlation coefficient was used to measure the degree of linear dependence between the two variables: ANNs output and THV. The correlation coefficient ranges from -1 to 1. A correlation coefficient value close to ±1 shows a good relationship between THV and the neural network output. This implies that the neural network works well in grading men's suiting fabric hand based on the mechanical properties. On the other hand, a correlation coefficient value close to zero may indicate that there is no strong relevance between the Kawabata THV and ANN hand grading values. However, it does not mean that the established ANN model is meaningless. Instead, it just reveals that the ANN criterion to define the best and worst fabric hand is different from that of the Kawabata THV. Therefore, the ANN approach is more practical and flexible for the apparel industry to select its own criterion or to dynamically update its training dataset for fabric hand/quality prediction.

Chapter 4 Results and Discussion

In this chapter, the data analysis and results are presented. The data were collected from the KES-FB and then processed in response to the research objectives listed in chapter 1 of this thesis. In order to meet the objectives of the study, quantitative approaches of the statistical methods were used to analyze data collected from the KES-FB and the neural network technique was applied to establish a prediction model for suiting fabric hand grade. These objectives were accomplished and the data analysis presented in this chapter answered the research questions and demonstrated the findings through this study.

4.1 Fabric Parameters and THV

In this study, the fabric mechanical and surface properties of the men's suiting fabrics were evaluated with the KES-FB instruments. These properties that represent fabric performance under low stress are summarized in Table 4.1. The total hand value (THV) of the collected suiting fabrics was calculated using the Kawabata equations for winter suiting fabrics. To increase the volume of the fabric sample dataset, an additional 18 suiting fabric samples were added to the original fabric sample dataset composed of 95 fabric samples. So the combined new dataset includes a total number of 113 fabric samples.

4.1 Mechanical Properties

The Kawabata data representing the mechanical properties of fabric samples was used to calculate Primary hand (HV) and Total hand value (THV) using Kawabata's equation KN-101-WINTER (Eqs.3.1 – 3.2). The averaged values of the mechanical properties are listed in Table 4.1. The details of measured mechanical properties are tabulated in Appendix-A.

As can be seen in Table 4.1, the selected woven and knitted suiting fabrics have similar fabric weight, though the fabric weight varies from sample to sample. Most knitted fabrics are thicker than the woven fabrics in this study.

Tensile and Shear Property

In terms of tensile property, knits have an inherently higher elongation (LT) than the woven. The tensile energy (WT) of woven and knitted samples is similar. Notably, the shear properties of the woven and knitted suiting fabrics are substantially different. Generally, the woven suiting fabrics have higher shear rigidity than the knitted fabrics, meaning that they are less likely to be distorted when stretched. Also, the woven fabrics have lower 2HG and 2HG5, the hysteresis of shear force at 0.5° and 5°, indicating that the woven fabrics have a better recovery from shear deformation.

Bending Property

With a similar value of bending rigidity B, the woven and knitted suiting fabrics have similar performance of resistance to a bending deformation. However, the woven suiting fabrics have a better recovery from bending deformations because of lower values of the hysteresis of the bending moment, 2HB.

Compression

Generally, the fabric compressive properties are highly related to the fabric hand in terms of fabric softness and fullness. In this study, the woven and knitted suiting fabrics have similar compressional properties LC (Linearity of compression-thickness curve) and RC (the compression resilience). However, the knitted fabrics require higher compressional energy per area, WC. This may be because the knitted suiting fabrics in this study are mostly thicker than the woven suiting fabrics.

Surface Property

As shown in Table 4.1, the woven and knits have similar measure of surface friction (MIU). Overall, woven fabrics in this case are geometrically rougher than knitted fabrics.

Table 4.1 Mean value of tested fabric mechanical parameters and THV

Parameters	Fabric Type		
	Woven	Knit	All
LC	0.3643	0.3002	0.3216
WC	0.1435	0.4777	0.2549
RC	60.9113	56.3115	59.3781
T	0.6439	1.3012	0.863
W	25.1661	30.0002	26.7775
LT	0.8253	1.4868	1.0458
WT	21.6543	20.0192	21.1093
RT	58.574	42.6792	53.2757
G	0.6149	2.5065	1.2454
2HG	0.6178	4.492	1.9092
2HG5	1.3267	5.256	2.6364
B	0.0952	0.1204	0.1036
2HB	0.0329	0.1153	0.0604
MIU	0.1927	0.2522	0.2126
SMD	1.9693	0.0321	1.3236
MMD	2.2499	3.5314	2.6771
THV	2.3771	2.5941	2.435

4.1.2 Primary Hand and Total Hand Value Calculation

Primary hand value (HV) and total hand value (THV) were obtained from the Kawabata's translation equation KN-101-WINTER for men's winter suit fabrics. Table 4.1 and Figures 4.1 show the distribution of HV and THV for all tested fabric samples. THV of a total number of 113 suiting fabrics follows a normal distribution with a standard deviation of 0.977 (Figure 4.1). The average THV of the tested samples is 2.435. Most suiting fabric samples in this study have an average hand of 2.435 indicating that these samples exhibit an average performance of hand. Notably, the average THV of knitted suiting fabrics is 2.594, slightly higher than the THV of the tested woven suiting fabrics, 2.3771.

THV of the fabric samples in the original dataset also shows a fairly good normal distribution with a standard deviation of 0.808 (Figure 4.2). As Figure 4.3

shows, the distribution of the THV of knits is slightly positive (right) skewed as the mean THV is higher than the median THV. This indicates that the hand quality of knitted samples is not as stable as the woven samples. Also, the THV distribution of the added samples shows a slightly negative (left) skewed curve. Comparing to the THV distribution of the total dataset, the skewed curves may be explained by small sample sizes.

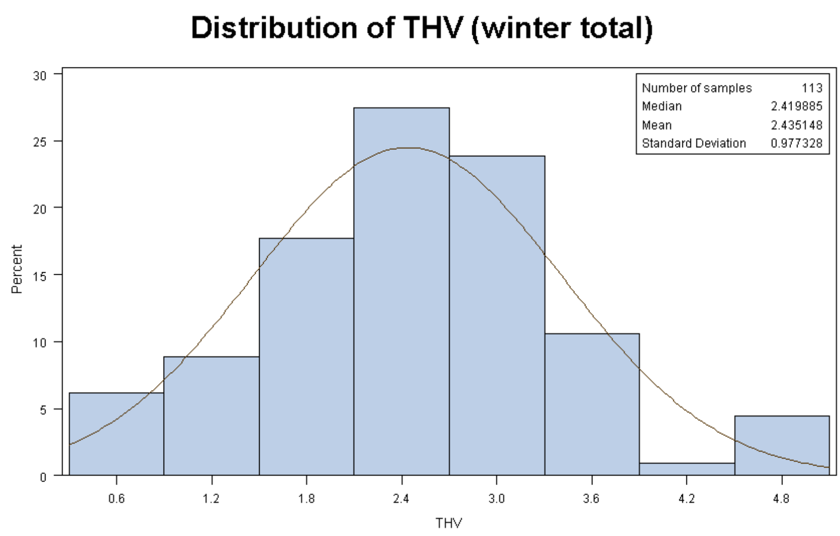

Figure 4.1 Distribution of THV (all samples)

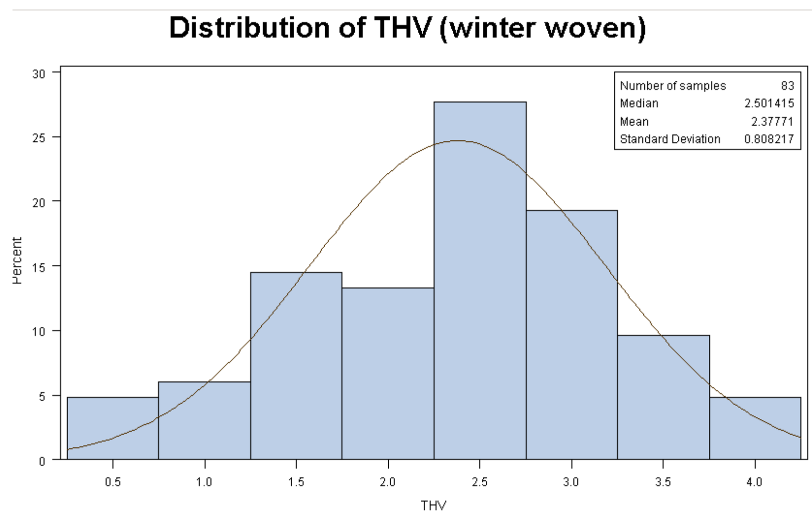

Figure 4.2 Distribution of THV (woven)

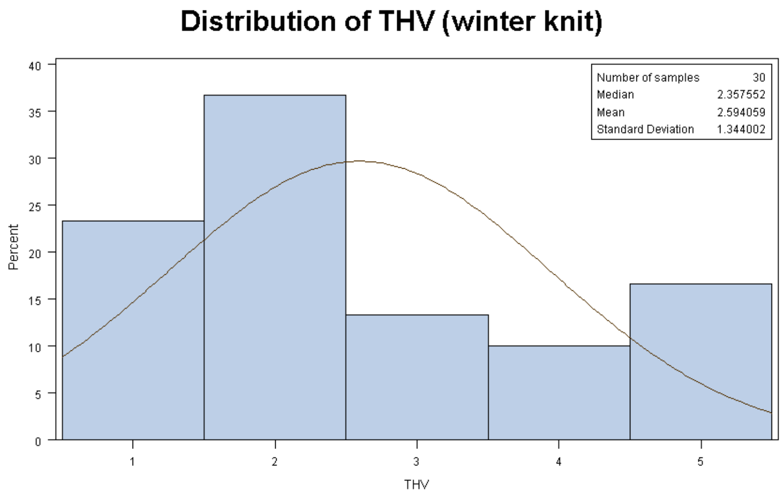

Figure 4.3 Distribution of THV (knits)

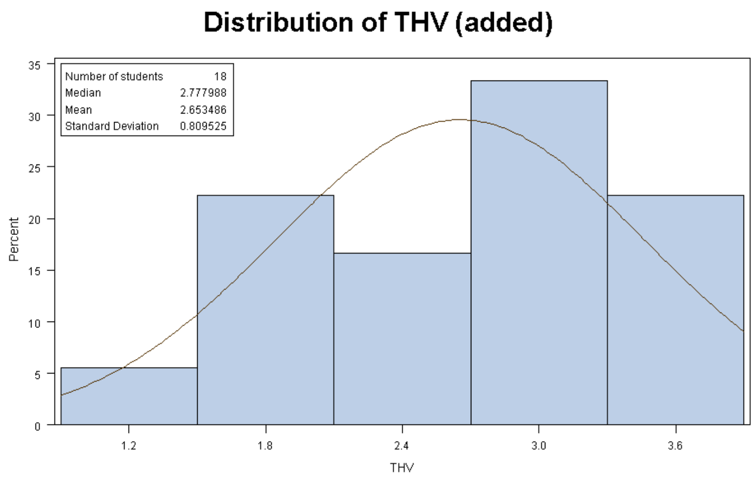

Figure 4.4 Distribution of THV (added samples)

4.2 Cluster Analysis

Unlike many other statistical methods, cluster analysis can be used for solving classification problems without prior information about group membership. In this study, the 113 suiting fabric samples were grouped by the SAS clustering procedure with the 16 fabric mechanical properties as clustering variables. The fabrics were clustered into three groups and four groups, respectively, based on a K-means method. Usually, the best number of clusters K leads to the greatest distances between groups indicating a best separation among the K clusters. The 3D plots of the two clustering results are shown in Figure 4.5 and Figure 4.7. Clusters with sample ID labeled are shown in Figure4.6 and 4.8. The summary of cluster analysis is shown in Table 4.2 and 4.3. The frequency of sample distribution in the two clusters is shown in Table 4.4 and Table 4.5.

Generally, both the three-group clusters and four-group clusters are well separated with little overlapping. As shown in Table 4.3, the distances between Group 1 and Group 4 in the four-group clusters are larger than those of the three-group clusters, indicating that the knits and woven are more separated in the four-group clusters (see Figure 4.7 and Figure 4.8). Also, the average values of the 16 mechanical properties show distinct difference among different group in four-group clusters (Table 4.6).

By evaluating the size and dispersion of each group, the four-group cluster result is considered a better way for grouping the suiting fabric samples in this study. Therefore, the selection of the training dataset for neural network evaluation in this study is based on the four-group clustering result.

As shown in Figure 4.7 and Table 4.5, the total 113 samples are divided into 4 groups. Group 1 and Group 4 have the least number of samples and largest distances from other groups. Most of the fabric samples fall into Group 2 and Group 3, with similar mechanical characteristics. According to the clustering results, Group 2 and Group 3 can best represent the regular men's suiting fabrics. Therefore, a training dataset for the neural network analysis is selected from Group 2 and Group 3.

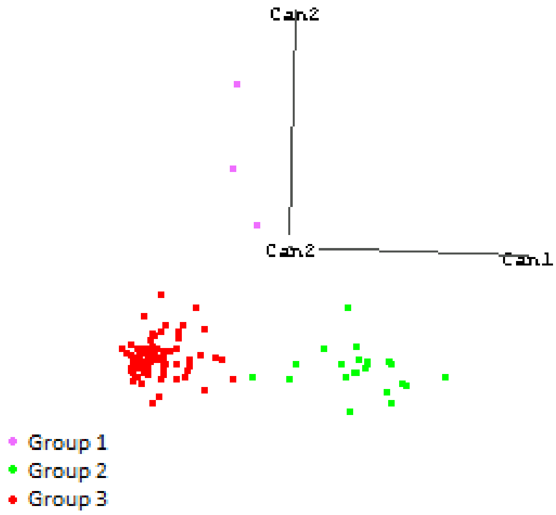

Figure 4.5 3D Plot of three-group cluster distribution

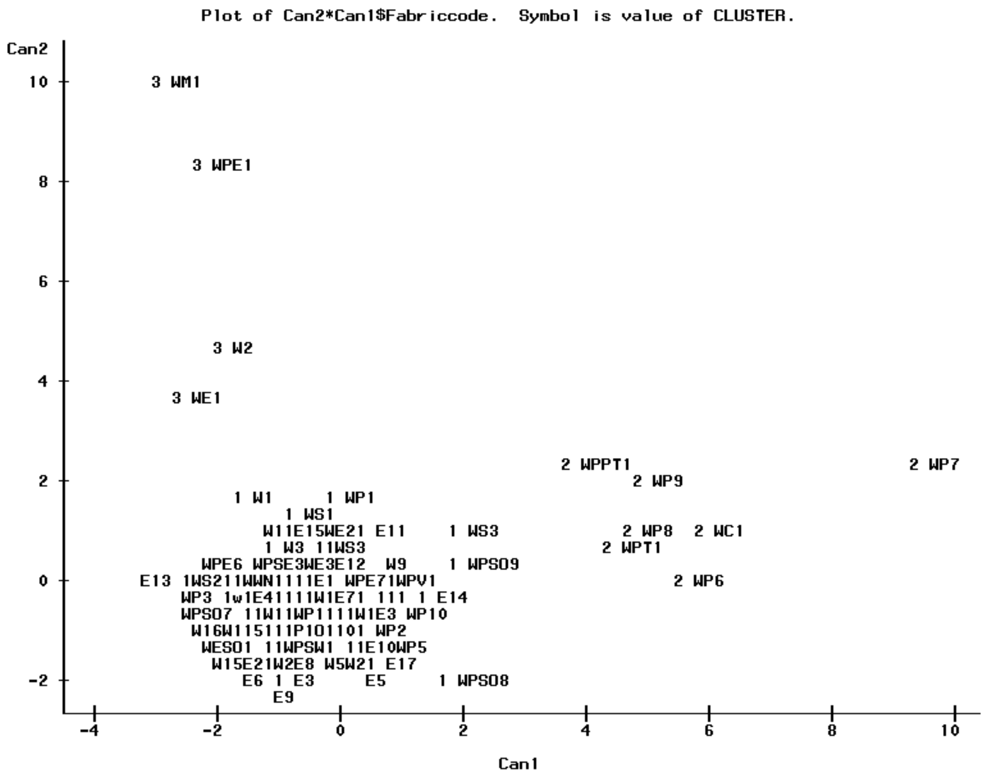

Figure 4.6 Plot of three-group cluster distribution (Sample ID labeled)

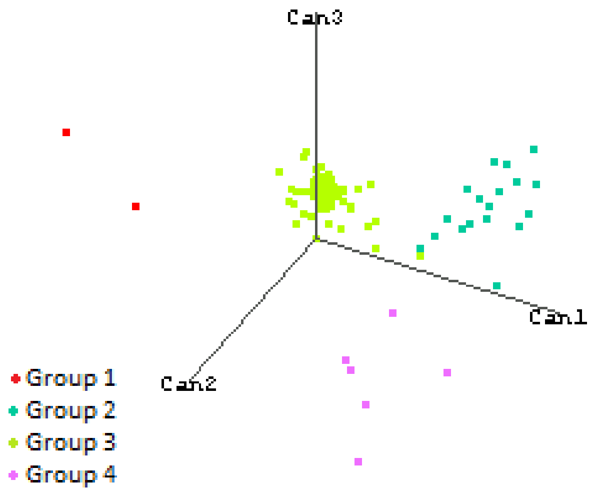

Figure 4.7 3D Plot of four-group cluster distribution

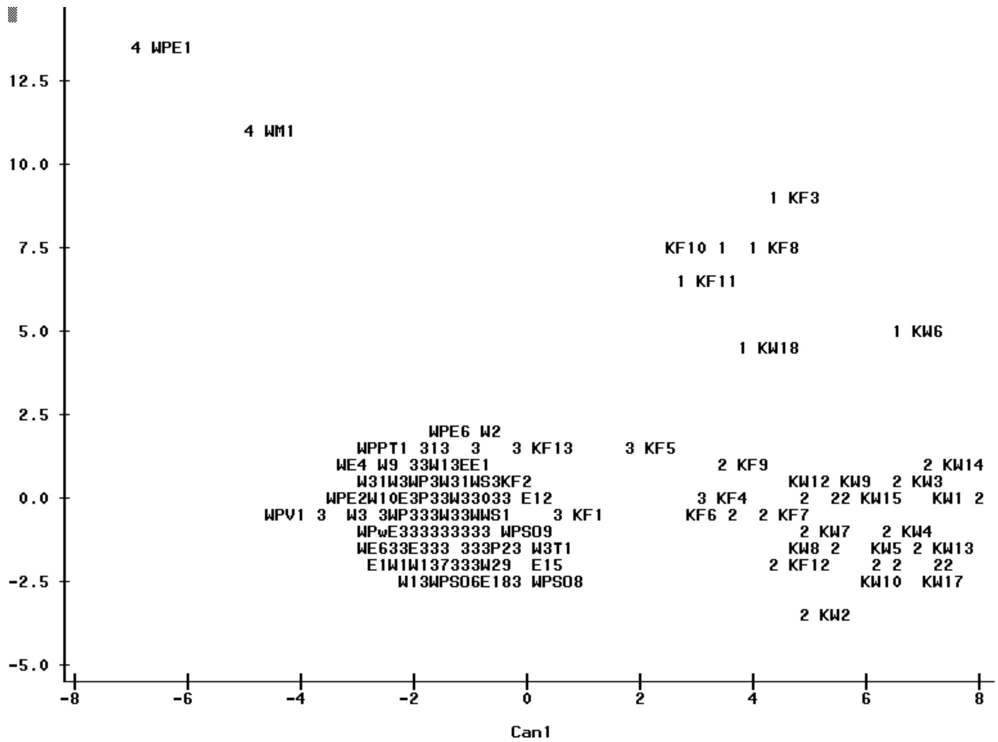

Figure 4. 8 Plot of four-group cluster distribution (Sample ID labeled)

Specifically, as shown in Table 4.3 and Table 4.5, most knitted samples (19 out of 30) fall into Group 2 and their average of THV is 3.796. On the other hand, most woven samples (81 out of 83) and 5 knits samples are grouped into Group 3 with an average THV of 2.061. Among the suiting fabric samples tested in this study, the knits generally show better hand than the woven.

Table 4.2 Cluster Summary (three-group cluster)

Cluster Centroids	Frequency	RMS Standard Deviation	Maximum Distance	Nearest Cluster	Distance between Cluster	THV
1	3	1.2882	5.1371	3	7.5325	2.2115
2	22	0.9869	5.3281	3	5.6998	3.0194
3	88	0.7021	4.9759	2	5.6998	2.2966

Table 4.3 Cluster Summary (four-group cluster)

Cluster Centroids	Frequency	RMS Standard Deviation	Maximum Distance	Nearest Cluster	Distance between Cluster	THV
1	6	0.8398	4.0196	2	5.0735	3.5234
2	19	0.8610	4.9147	1	5.0735	3.7963
3	86	0.6984	7.0600	2	5.4597	2.0613
4	2	0.9192	2.6000	1	8.8360	2.1623

Table 4.4 Frequency of three-group cluster distribution

Cluster	Knit	Woven	Total
1	1	2	3
2	22	0	22
3	7	81	88
Total	30	83	113

Table 4.5 Frequency of four-group cluster distribution

Cluster	Knit	Woven	Total
1	6	0	6
2	19	0	19
3	5	81	86
4	0	2	2
Total	30	83	113

Table 4.6 Summary of Mechanical parameters of four-group clusters

Fabric Type	Group 1	Group 2	Group 3	Group 4
LC	0.3796	0.3172	0.3162	0.29
WC	0.3129	0.206	0.2376	0.2333
RC	56.195	58.28	60.499	69.526
T	0.9043	0.7763	0.823	0.907
W	25.3161	26.7446	29.519	30.863
LT	1.047	0.9447	1.104	1.2
WT	18.464	22.91	25.328	32.095
RT	53.56	51.276	52.358	52.334
G	2.2378	1.8681	0.902	1.0304
2HG	3.862	3.2718	1.214	1.4608
2HG5	3.792	4.072	1.9824	2.1703
B	0.0951	0.0908	0.1109	0.1096
2HB	0.0555	0.0661	0.0571	0.0842
MIU	0.2217	0.2244	0.2064	0.1406
SMD	0.485	1.1398	2.609	2.404
MMD	2.995	2.0282	1.5186	1.2774
THV	3.5235	3.7962	2.0614	2.1624

4.3 Neural Network Model

4.3.1 Hand Index

First, the machine learning was processed using the KES-FB instrumental data of the two target groups of suiting fabric samples, representing the best hand (1) and worst hand (0) respectively. Table 4.7 lists the information of the training dataset and test dataset in this study. The training dataset, consists of 65 samples, was selected from Group2 and Group 3 in the four-group clusters. Among all the samples in Group2 and Group3, 30 samples have a THV higher than 2.9 and 35 have a THV lower than 1.9. Then, they were selected as the training dataset to represent the best hand and worst hand, respectively. The rest of the 113 samples constitute the test dataset.

Table 4.7 Training dataset and test dataset

Dataset Type	Hand Index	Number of Samples	Cluster Origin	THV
Training	1	30	Group2, 3	>2.9
	0	35	Group2, 3	<1.9
Test	0-1	48	All groups	

By learning from the inputs, an artificial neural network configures itself with statistical trends of the inputs. Then, with the multilayer perceptron (MLP) model, the neural network model is able to produce a value between 0 and 1 to grade the hand of test dataset. The output of the neural network model is defined as Hand Index in this study. The Hand Index is a value between 0 and 1 to grade fabric hand based on the measured mechanical properties. It is hypothesized that the higher the Hand Index is, the better hand has the fabric. To validate this hypothesis, the correlation between Hand Index and THV is examined in the last part of Chapter 4.4 Correlation of Hand Index and THV. Table 4.8 shows the input parameters for neural network modeling.

The information of the learning curve of the training process is shown in Figure 4.9. Table 4.9 shows that MSE is as small as 4×10^{-8} indicating a highly accurate training model. The implementation of this model indicated that the neural network approach was successful in grading fabric hand based on the Kawabata's instrumental data.

Table 4.8 Input parameters for neural network modeling

Fabric Parameter	Input	Fabric Parameter	Input
Compression Linearity LC	X_1	Shear stiffness G (gf/cm·degree)	X_9
Compression Energy WC (gf·cm/cm^2)	X_2	Shear Hysteresis at 0.5^0 2HG (gf/cm)	X_{10}
Compression Resilience RC (%)	X_3	Shear Hysteresis at 5^{0}2HG5 (gf/cm)	X_{11}
Fabric Thickness	X_4	Bending rigidity B (gf·cm^2/cm)	X_{12}
Weight (g/ m^2)	X_5	Bending Hysteresis 2HB (gf·cm^2/cm)	X_{13}
Tensile Linearity LT	X_6	Coefficient of friction MIU	X_{14}
Tensile Energy WT (gf·cm/cm^2)	X_7	Mean Deviation of MMD	X_{15}
Tensile Resilience RT (%)	X_8	Mean Surface Roughness SMD	X_{16}

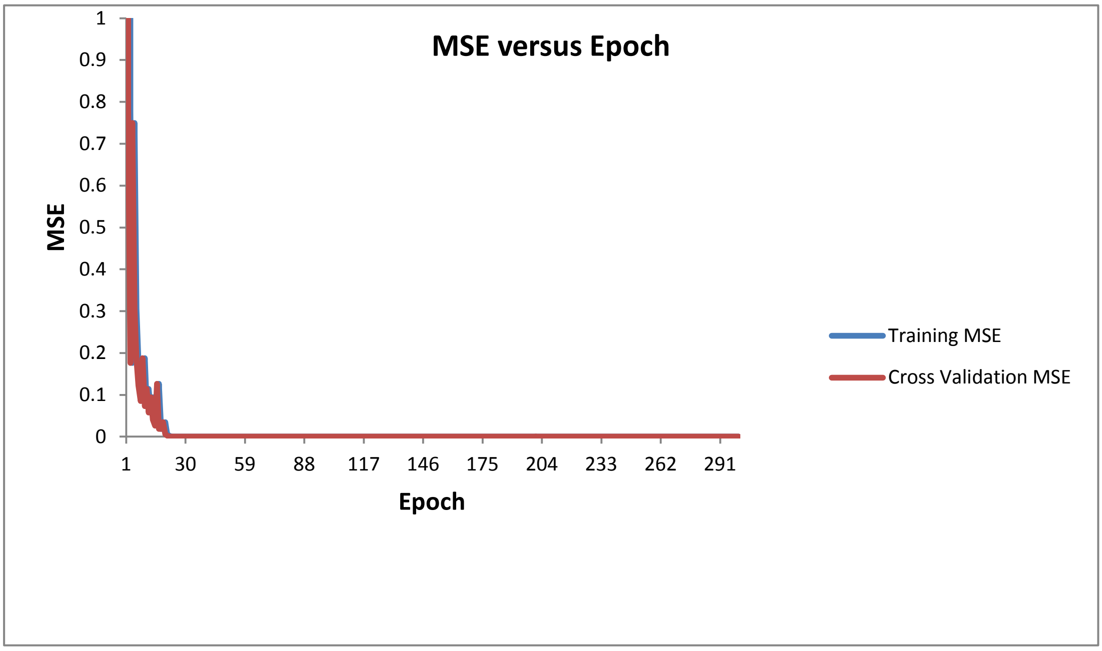

Figure 4.9 Neural Network model learning curve

Table 4.9 Epoch and MSE of the learning curve

Best Networks	Training	Cross Validation
Epoch #	128	127
Minimum MSE	0.00000004	0.00000004
Final MSE	0.00000004	0.00000004

This study describes a neural network approach to model the hand grading by giving a hand grade called Hand Index based on fabric mechanical properties. The output of the neural network model is listed in Appendix-C. The average Hand Indexes of the test samples of the four clustering groups are listed in Table 4.10 with comparison with THV and normalized scaling THV. The normalization of THV by scaling between 0 and 1 is calculated by the Equation 4.1. As can be seen in the Table 4.10, the grading results of the samples from Group 1, Group 2 and Group 3 are similar to that of THV grading. However, the Hand Index of the samples of Group 4, is significantly different from hand grading by THV. This may be explained by the clustering results that show a great distance of Group 4 from other groups indicating a substantial difference in fabric mechanics. Only two samples in Group 4 are considered not suitable for being used as men's suiting fabric. Since the two samples of Group 4 are not representative of the application of grading suiting fabrics, they are eliminated from the resulting neural network output when comparing to THV in the next chapter.

$$\text{Normalized } (e_i) = \frac{e_i - E_{min}}{E_{max} - E_{min}} \quad (4.1)$$

where

E_{min} = the minimum value for variable E

E_{max} = the maximum value for variable E

If E_{max} is equal to E_{min} then *Normalized* (e_i) is set to 0.5.

Table 4.10 Hand Index graded by neural network model

	Target #1	Group 1	Group 2	Group 3	Group 4	Target #2
Hand Index	0	0.2413	0.3102	0.4961	0.5455	1
THV	1.2862	1.9875	2.3443	2.4554	1.8503	3.5196
Normalized THV	0	0.3140	0.4738	0.5235	0.2526	1

4.3.2 Correlation of Hand Index and THV

The correlation between the Hand Index by neural network model and THV was examined by SAS regression procedure. Stepwise method was used for the linear regression analysis. By doing the linear regression analysis, the Hand Index grading can be compared to Kawabata's THV grading.

In the regression process of the total 48 samples in the test dataset, two outliers (Sample WPE1 and KF11) were found. As shown in Figure 4.10, these two observations have large distance from the regression line. From the Fit diagnostics (Figure 4.11(F)), the plot of the Cook's D statistic shows that Observations 1 and 2 (WPE1 and KF11) noticeably exceed the threshold value indicating that they have a great influence on the regression parameter estimates. This is due to the distinct difference of the mechanical performance of

WPE1 and KF11 as opposed to other fabric samples in this study. Also, in the cluster analysis (Figure 4.8), WPE1 has a large distance from other samples in this study. Because of the reasons listed above, WPE1 and KF11 are considered inappropriate in men's suiting application. Therefore, in the correlation examination between Hand Index and THV, these two samples are not included.

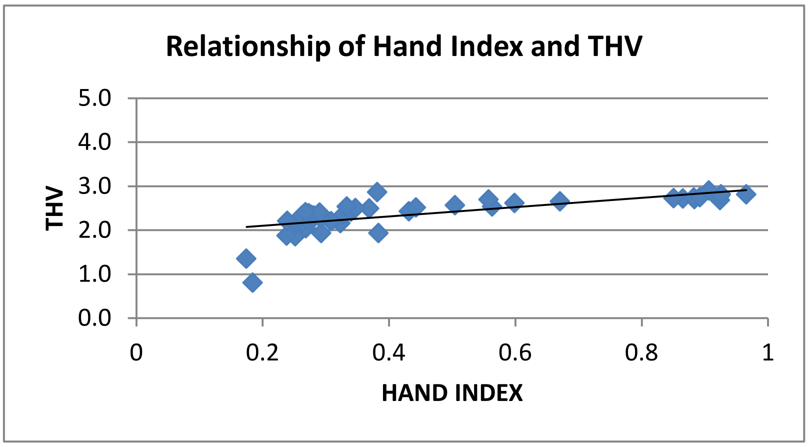

Figure 4.10 Simple linear regression of Hand Index and THV (48 samples)

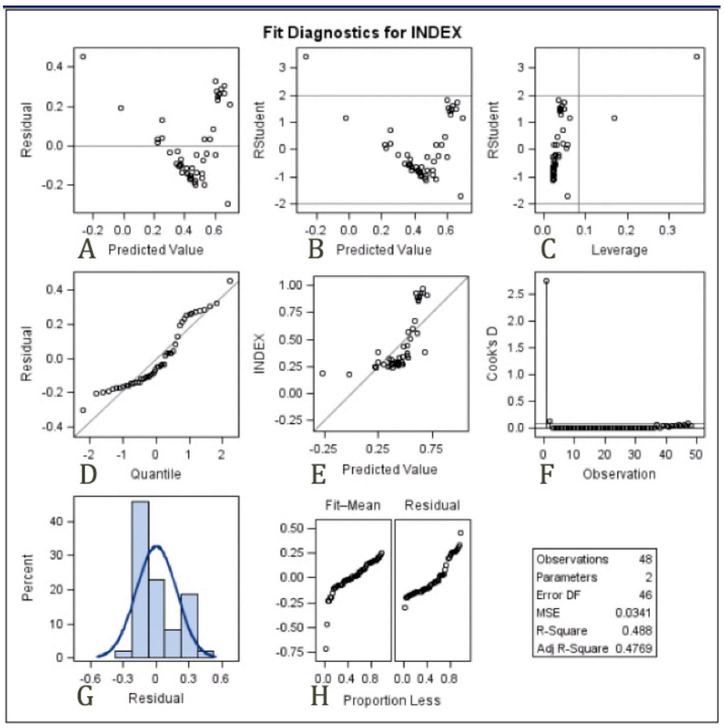

Figure 4. 11 Fit Diagnostics for Hand Index (48 Samples)

The regression result of the 46 samples in the test dataset is summarized in Table 4.11 and Table 4.12. From the results, it is notable that THV is highly related to the hand index ($p<0.0001$). The overall F statistic is significant ($F=76.98$, $p<0.0001$). It can be concluded that there is a high correlation between the Hand Index and THV.

Figure 4.12 displays the fitted line from the results of simple regression. As Figure 4.12 and Table 4.12 show, the fitted line does not naturally go through the origin. The equation of the regression line is listed at Equation 4.2. Figure 4.14 shows the Fit plot consists of a scatter plot of the data by the regression line and a 95% confidence and prediction limit line. It can be seen in the Figure 4.14 that all of the observations fall in the 95% prediction limit.

In general, the higher R-squared the model has, the better the model has. In this correlation analysis, with a R^2 value of 0.6363, it can be seen that there is a considerably strong correlation between the hand index and THV.

Table 4.11 Analysis of Variance of the Regression model

Source	DF	Sum of	Mean Square	F value	Pr>F
Model	1	1.85182	1.85182	76.98	<0.0001
Error	44	1.05840	0.02405		
Corrected Total	45	2.91022			

Table 4.12 Parameter Estimates

Variable	DF	Parameter	Standard	t Value	Pr>|t|
Intercept	1	-1.32224	0.20471	-6.46	<0.0001
THV	1	0.73805	0.08412	8.77	<0.0001

The equation of the regression line is:

$$y = 2.019 + 0.862x \tag{4.2}$$

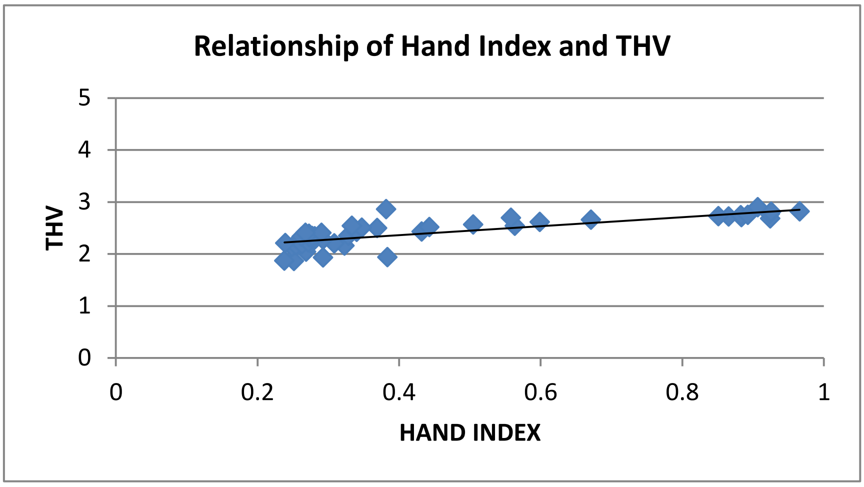

Figure 4.12 Simple linear regression of Hand Index and THV (46 samples)

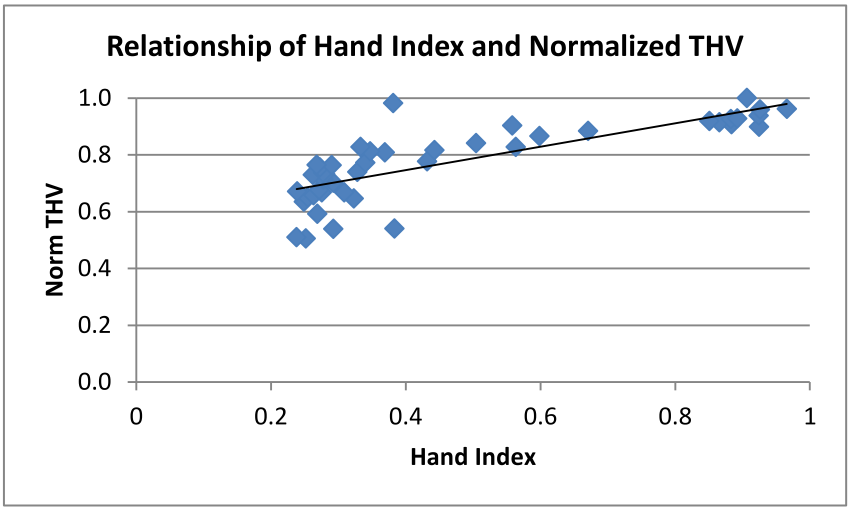

Figure 4.13 Simple linear regression of Hand Index and Normalized THV

Table 4.13 Summary of the Fit Plot for Hand Index

Observations	Parameters	Error DF	MSE	R-Square	Adj R-Square
46	2	44	0.0241	0.6363	0.628

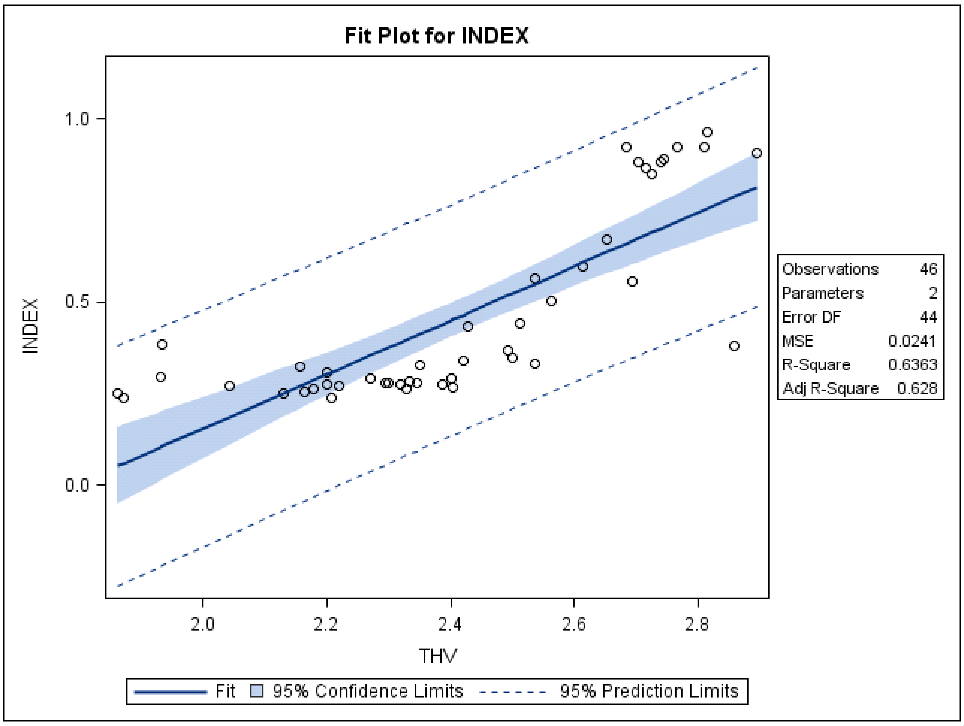

Figure 4.14 Fit Plot for Hand Index

The residual plot (Figure 4.15) shows the residuals form an approximate U-shaped curve suggesting a better fit for a non-linear model. Regarding the normality of the residual distribution, there is an approximately normal distribution of the residuals. This validates the model by explaining the variability in the outcome as predicted by the model. Overall, the fit of the observations to the linear regression line (Figure 4.13) and the residual plot (Figure 4.15) indicate a possible non-linear model. However, more data is needed for setting up an accurate regression model with a good fit.

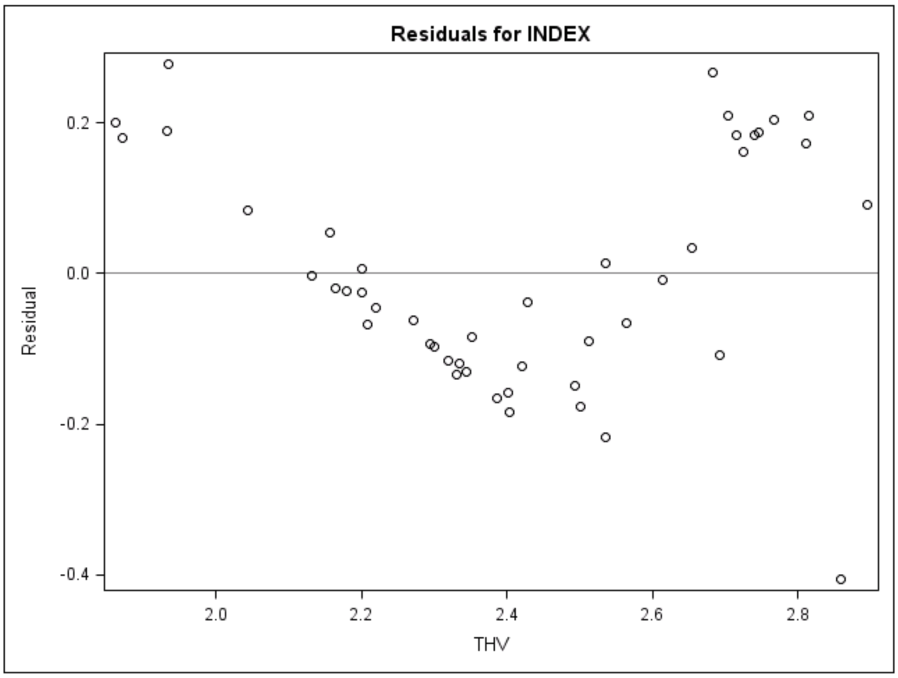

Figure 4.15 Residual Plot

Chapter 5 Conclusions and Suggestions for Further Work

5.1 Conclusions

In this study, an objective approach for evaluating the hand of men's suiting fabrics was investigated. Ninety five commercial suiting fabrics, including 65 woven fabrics and 30 knitted fabrics, were selected and tested in terms of different mechanical properties using the KES-FB instruments. With the data from the KES-FB, the mechanical properties of the woven and knitted fabrics were compared and classification of the fabric samples was conducted using cluster analysis. With the results from cluster analysis and THV given by the Kawabata's equation, a neural network model was established to grade fabric hand with a numerical value defined as Hand Index in contrast to THV. A comparison of the mechanical properties between the woven and knitted fabrics was also conducted.

The study found that the knits have better hand with lower shear rigidity (G), higher compression energy (WC) and rougher surface. In terms of tensile properties, woven and knitted suiting fabrics do not show much difference. In terms of tensile properties, the knitted fabrics are similar to woven fabrics in tensile energy (WT) and resilience (TR), but show a larger extensibility. Moreover, the knitted fabrics are more subject to shear deformation, having much lower values of shear rigidity (G), and larger shear hysteresis (2HG and 2HG5) than the woven fabrics.

With the results of clustering analysis, the men's suiting fabric samples were classified into four groups based on their mechanical properties. The clusters are naturally separated without much overlapping. The mechanical properties for each group are distinct from each other, indicating a good result of classification. Group 2 and Group 3 are considered appropriate for being used as commercial men's suiting fabrics. Group 3 consists of all the woven fabric samples with lower shear rigidity (G) and lower shear hysteresis (2HG and 2HG5). The fabrics (mostly knits) in Group 2 have higher hand value. In general, the classification process using cluster analysis in SAS successfully divided the woven and knitted suiting fabrics without prior knowledge. This classification result also indicates the distinct difference between the woven and knitted suiting fabrics. However, the warp and filling knits do not show much difference in mechanical properties and they are naturally dispersed in Group 2 and Group 3. It can be concluded that the clustering analysis is helpful in sorting suiting fabrics into different groups according to their mechanical properties.

Along with the THV, the classification result was used for assigning fabric samples to training dataset and test dataset for neural network evaluation. The neural network technique using MLP method was performed to grade suiting fabrics in this study. With a MSE as low as 4×10^{-8}, the model is highly accurate in predicting the hand based on the KES-FB data in the training dataset. Then, the neural network model gave a numerical hand grade called Hand Index that ranges from 0 to 1 for each sample in the test dataset. To validate the hand grading method by the neural network method, the correlation between Hand Index and THV was examined using a linear regression model. From the fact that R square equals 0.6363 and $p<0.0001$, it can be concluded that there is a positive linear association between the Hand Index and THV. This indicates that fabric hand can be estimated well with the neural network technique. However, the residual plot (Figure 4.12) shows the residuals do not follow a random pattern suggesting a better fit for a non-linear model.

5.2 Suggestions for Future Work

Apart from most commonly used men's suiting fabrics, the demand for more variety of suiting fabrics such as knits is increasing. However, the process of selecting appropriate fabrics for making men's suits is usually subjective and based on designers' or quality control specialists' experience. Therefore, the hand evaluation on suiting fabric using the KES-FB instrumental data and the clustering process can be applied by designers and manufacturers. Also, to meet the growing need for higher apparel quality in suiting apparel production, the method using neural network model to grade suiting fabrics in this study is recommended. The implications of the work for future research are described below.

1. Despite the good correlation between Hand Index and THV of suiting fabrics in this study, more data is needed to substantiate this association.
2. In the neural network model for grading in this study, to better grade men's suiting fabric samples, a larger dataset to train the neural network model is needed.
3. The results of the correlation between Hand Index and THV show a great potential for the neural network model to expedite the process of fabric hand grading dynamically. The neural network approach can deal with both linear and non-linear systems. Researchers are able to examine the relationship between different mechanical parameters and fabric hand by choosing different parameters as inputs in the neural network model.
4. Researchers and manufacturers should collaborate in order to develop better suiting products made of knitted fabrics. The similarity and dissimilarity between woven and knitted suiting fabrics should be further examined by studying the inter-relationship within their mechanical properties.
5. The neural network model used for grading men's suiting fabric hand in this research can be applied to other fabric end-uses with further research

on different fabric types. Moreover, the study can be extended to other fabric properties such as fabric tailorability and drape by using different parameters as inputs in the neural network model.

6. Further efforts can be made to introduce the KES-FB and the neural network model to the clothing industry. This will help manufacturers establish their own fabric database for documentation of fabric quality and prediction of fabric processability and end uses. For example, after setting up the training dataset with previous fabric products, manufacturers would be able to grade every new fabric by using the neural network model based on their own database.

Appendices

A. Kawabata Test Result for 113 Fabric Samples

Code	Fabriccode	Enduse	LC	WC	RC	T	W	LT
1	W13	S	0.267667	0.105667	71.00067	0.550667	32.5	1.1076
2	WPE3	S	0.325333	0.143667	52.025	0.566667	27.5	0.999783
3	W3	S	0.311667	0.289	60.56033	1.011667	34.5	0.585717
4	WP4	S	0.298333	0.120333	56.91867	0.607667	34	0.9836
5	W7	S	0.309	0.103	69.78267	0.543667	32.5	1.080367
6	W11	S	0.289333	0.259333	56.699	0.984667	34.5	0.805217
7	W10	S	0.305333	0.133333	65.92733	0.621333	29	1.016367
8	WN2	S	0.272	0.129333	56.9411	0.616667	35.5	0.99915
9	WS1	S	0.295333	0.179667	60.14167	0.861667	28	1.070533
10	WP1	S	0.265667	0.320667	60.907	1.01	29	0.992017
11	W2	S	0.289667	0.435333	60.13433	1.365	30	1.005217
12	WE1	S	0.228	0.279333	61.485	1.223667	40	1.058217
13	WPSO1	S	0.323	0.136	61.41933	0.584	28.6	1.04015
14	W8	S	0.275667	0.112667	65.81667	0.525	26	1.039983
15	WN1	S	0.245333	0.190333	58.69	0.747667	36	0.951017
16	WP2	S	0.323667	0.126333	57.91867	0.534333	27.7	1.045217
17	WPV1	S	0.288	0.177	61.01533	0.778333	33.5	0.9006
18	W12	S	0.420333	0.116667	74.74567	0.472667	24.5	1.04405
19	WPE2	S	0.371	0.148667	53.40233	0.591333	27.5	0.788217
20	WC1	S	0.244333	0.154333	57.13833	0.797667	38	0.969367
21	WPT1	S	0.348333	0.104333	53.26333	0.511667	28.5	1.1046
22	W4	S	0.339667	0.109667	62.60567	0.441667	32.5	0.904983
23	W6	S	0.293	0.104667	68.654	0.482	26	1.039083
24	W5	S	0.325667	0.104333	62.80333	0.463333	29	0.989733
25	WPPT1	S	0.348333	0.154	56.94867	0.623	33	1.05885
26	WP3	S	0.301333	0.126	56.24033	0.583333	34	1.048467
27	WP5	S	0.408333	0.095667	63.33167	0.44	23.5	1.099533
28	W9	S	0.324667	0.091667	61.29467	0.433333	27	1.02475
29	WS2	S	0.247	0.140333	59.56167	0.754333	33	0.917683
30	WM1	S	0.363	0.461333	64.11133	1.595333	47.5	0.9991
31	W1	S	0.319	0.368	64.18167	1.103333	30	0.881917
32	WP10	S	0.347	0.118333	57.314	0.563333	33	1.01965
33	WPSO7	S	0.303333	0.117333	58.18633	0.493	26.5	1.07665
34	WPSO6	S	0.301667	0.117333	58.544	0.505667	26.5	1.074317
35	WE4	S	0.311333	0.117667	62.63	0.493	26.5	0.902
36	WPE7	S	0.264	0.107	59.94533	0.510333	28	1.027183

A. Kawabata Test Result for 113 Fabric Samples (Continued)

Code	Fabriccode	Enduse	LC	WC	RC	T	W	LT
37	WPSE3	S	0.305333	0.166	59.43633	0.658667	31	0.9984
38	W19	S	0.314333	0.108333	48.78	0.507	28.5	1.06965
39	W18	S	0.275667	0.103667	63.12267	0.468667	25.4	0.936083
40	W17	S	0.273333	0.116667	65.99	0.515	27	1.064083
41	WPSO5	S	0.331667	0.141333	59.69967	0.582	31	1.037833
42	WP9	S	0.258667	0.139667	59.20067	0.791333	42.5	1.107267
43	WS3	S	0.278333	0.138	56.94633	0.676667	28	1.086
44	WPSO9	S	0.292667	0.138667	53.517	0.609333	29	1.068417
45	WESO4	S	0.289	0.126	68.189	0.516667	26.5	1.061067
46	W21	S	0.333333	0.114667	71.72933	0.468667	22.7	0.907717
47	WE2	S	0.235667	0.197333	65.72033	0.980333	28.5	0.574383
48	WP8	S	0.293667	0.151	52.93667	0.746333	39	1.00915
49	W16	S	0.327667	0.105667	79.907	0.451667	25	1.071967
50	WP7	S	0.274333	0.136667	57.07667	0.760333	52.5	1.069
51	WS3	S	0.329	0.097667	62.84567	0.371667	28	0.998817
52	WPE5	S	0.268667	0.110667	69.34533	0.483667	26.5	0.9425
53	WPSE1	S	0.367333	0.096667	70.825	0.390667	28	0.927167
54	W15	S	0.327667	0.130333	59.32233	0.463667	25.4	0.967583
55	WPSO3	S	0.336	0.135	61.367	0.510333	27.4	1.007433
56	WPE4	S	0.279333	0.11	71.431	0.470667	26.5	1.025983
57	WPSO2	S	0.341333	0.119	57.20233	0.481667	27	1.058167
58	W14	S	0.294333	0.120333	66.785	0.521667	30	0.9508
59	WP6	S	0.285	0.118667	51.62033	0.578333	33	1.005967
60	W20	S	0.295667	0.094667	74.24833	0.406333	25	1.073667
61	WPSO8	S	0.336	0.108333	62.03567	0.456	23.9	1.19
62	WE3	S	0.303	0.163667	69.44267	0.722	28.5	0.839117
63	W22	S	0.283333	0.141333	59.52433	0.437667	29	1.119683
64	WPE1	S	0.360467	0.144667	56.94867	1.011667	67.5	1.042333
65	WPE6	S	0.253667	0.112333	56.46567	0.524	28	1.0306
66	E1	S	0.367	0.1355	49.3315	0.6415	21.2	0.56955
67	E2	S	0.2895	0.107	52.297	0.6065	20.3	0.5548
68	E3	S	0.3315	0.129	60.2265	0.4515	14.9	0.59745
69	E4	S	0.3115	0.1895	61.6085	0.8015	20.1	0.6161
70	E5	S	0.2645	0.079	50.4975	0.5115	18.4	0.5894
71	E6	S	0.2685	0.1055	72.999	0.524	18.6	0.6766
72	E7	S	0.2965	0.1415	65.8365	0.6775	23.7	0.6634
73	E8	S	0.343	0.1505	59.7935	0.6085	18.8	0.59225
74	E9	S	0.3145	0.1575	61.0425	0.52	13.6	0.5466
75	E10	S	0.2425	0.129	64.7495	0.626	21.2	0.54665

A. Kawabata Test Result for 113 Fabric Samples (Continued)

Code	Fabriccode	Enduse	LC	WC	RC	T	W	LT
76	E11	S	0.288	0.1315	59.958	0.6485	25.8	0.7987
77	E12	S	0.2705	0.1795	52.801	0.813	19.2	0.778
78	E13	S	0.3395	0.1785	55.526	0.86	21.0	0.5145
79	E14	S	0.288	0.163	56.2205	0.7555	24.5	0.61235
80	E15	S	0.213	0.1455	64.0935	0.9055	15.9	1.189441
81	E16	S	0.358	0.1185	63.9295	0.518	16.3	0.6007
82	E17	S	0.3015	0.092	68.7595	0.474	19.6	0.60275
83	E18	S	0.2275	0.1255	64.3535	0.7315	18.1	0.68975
84	KF1	K	0.339333	0.301	55.32433	1.277	26.077	1.33935
85	KF2	K	0.311333	0.356	69.706	1.329333	35.225	1.458025
86	KF3	K	0.527667	1.283333	53.426	2.469667	43.1525	1.326
87	KF4	K	0.333333	0.350333	68.16067	1.106833	30.855	2.0051
88	KF5	K	0.355333	0.369667	67.066	1.017333	30.21	1.768483
89	KF6	K	0.286	0.257333	60.87367	1.034667	37.325	2.030633
90	KF7	K	0.319	0.322333	66.92833	1.285333	28.4775	2.024383
91	KF8	K	0.324	0.921333	52.16367	2.242667	34.47	1.793167
92	KF9	K	0.399333	0.390333	55.25267	0.901667	27.505	1.92125
93	KF10	K	0.291667	0.868667	60.77033	2.457667	34.55	1.936249
94	KF11	K	0.435667	0.767	53.498	1.655333	30.85	1.725025
95	KF12	K	0.308	0.238333	56.111	0.705333	18.89575	1.31935
96	KF13	K	0.101667	0.362	71.90433	1.986	45.825	1.315417
97	KW1	K	0.379333	0.344333	49.57533	0.906	29.54275	1.247833
98	KW2	K	0.295667	0.188667	52.35433	1.016667	27.865	1.186317
99	KW3	K	0.462	0.444667	49.64	0.963333	24.942	1.24815
100	KW4	K	0.364	0.370667	60.736	0.668667	24.875	1.325667
101	KW5	K	0.550667	0.592333	50.423	1.731667	30.9925	1.406492
102	KW6	K	0.517	1.054667	44.48733	1.453667	27.961	1.350575
103	KW7	K	0.334333	0.341667	57.84333	1.031667	26.37675	1.299958
104	KW8	K	0.329667	0.465667	60.693	1.256333	27.68	1.322475
105	KW9	K	0.43	0.471	58.79433	1.236	28.49	1.2641
106	KW10	K	0.428667	0.298333	51.54467	1.110667	29.355	1.28435
107	KW11	K	0.257667	0.305333	50.252	1.253667	30.9825	1.241525
108	KW12	K	0.22	0.350667	50.69167	1.289667	24.765	1.184617
109	KW13	K	0.358333	0.43	48.66567	1.148667	25.477	1.304525
110	KW14	K	0.496	0.750333	46.31133	1.29	27.045	1.396033
111	KW15	K	0.393667	0.42	56.275	0.824333	29.26975	1.298642
112	KW17	K	0.386333	0.243333	51.159	0.786333	27.60425	1.238125
113	KW18	K	0.393333	0.473	58.714	1.599667	33.366	2.043

A. Kawabata Test Result for 113 Fabric Samples (Continued)

Code	Fabriccode	Enduse	WT	RT	G	HG	HG5	B
1	W13	S	25.3588	57.18523	0.806217	0.59865	1.100933	0.072165
2	WPE3	S	43.0012	67.46145	0.6391	1.003067	1.477083	0.055627
3	W3	S	26.01827	50.21698	0.364433	0.475817	0.68705	0.085559
4	WP4	S	24.02142	51.64378	0.586667	0.73965	1.444833	0.113726
5	W7	S	30.58108	49.54648	0.66135	0.58145	1.0799	0.093483
6	W11	S	29.6252	37.19488	0.369417	0.565367	0.856367	0.084742
7	W10	S	18.32272	56.27468	0.45595	0.371967	0.802567	0.100279
8	WN2	S	21.98715	55.32775	0.557367	0.608783	1.114167	0.109132
9	WS1	S	28.80667	49.41648	0.457833	0.549217	1.076283	0.087382
10	WP1	S	23.79335	48.06122	0.4006	0.606167	1.024967	0.079833
11	W2	S	48.25907	40.541	0.473633	0.717667	1.040817	0.088625
12	WE1	S	52.03052	39.52348	0.5587	0.665383	1.094783	0.103867
13	WPSO1	S	34.01	58.02183	0.494017	0.61535	1.050733	0.06225
14	W8	S	27.69583	54.63173	0.535583	0.535583	1.402233	0.0736
15	WN1	S	22.22647	60.36675	0.489733	0.454717	0.812833	0.099383
16	WP2	S	28.05493	53.38025	0.673883	0.77435	1.431067	0.066486
17	WPV1	S	23.81268	79.67928	0.482317	0.858567	1.302183	0.12025
18	W12	S	25.303	46.15263	0.661217	0.3994	1.100933	0.05976
19	WPE2	S	42.20855	73.00488	0.56755	0.854783	1.34215	0.056
20	WC1	S	19.72112	51.44855	1.076883	1.886082	3.09005	0.161067
21	WPT1	S	20.21288	54.58702	0.773117	1.184817	3.0467	0.081738
22	W4	S	22.55463	64.72817	0.70465	0.448077	1.218183	0.053117
23	W6	S	27.98235	53.25815	0.672817	0.6099	1.373717	0.0734
24	W5	S	24.86788	56.26298	0.65275	0.658133	1.309417	0.072917
25	WPPT1	S	26.3419	58.83585	1.241	1.26835	2.638833	0.126013
26	WP3	S	25.99057	52.77067	0.533367	0.66745	1.206917	0.255556
27	WP5	S	23.20182	54.05145	0.5513	0.479167	1.167583	0.06255
28	W9	S	24.25412	58.7305	0.606067	0.423267	1.129767	0.066245
29	WS2	S	34.91055	56.03838	0.429183	0.407983	0.736833	0.078
30	WM1	S	44.78555	42.91907	0.472867	0.760583	1.03325	0.445083
31	W1	S	27.10573	47.73972	0.382183	0.664967	0.8903	0.123562
32	WP10	S	30.80933	53.70333	1.107667	1.115833	1.895167	0.09635
33	WPSO7	S	34.58703	56.68555	0.513617	0.480183	0.918667	0.058944
34	WPSO6	S	22.8187	56.91898	0.542033	0.549167	1.157667	0.063783
35	WE4	S	38.78517	52.80047	0.6676	0.469017	0.994633	0.059633
36	WPE7	S	34.42217	57.8285	0.8973	0.701667	1.7955	0.096992
37	WPSE3	S	33.33572	56.61875	0.563167	0.673167	1.198	0.08
38	W19	S	39.37218	55.03798	0.808833	0.988733	1.852917	0.07465
39	W18	S	25.11217	53.90567	0.44375	0.353283	0.817333	0.0612

A. Kawabata Test Result for 113 Fabric Samples (Continued)

Code	Fabriccode	Enduse	WT	RT	G	HG	HG5	B
40	W17	S	28.01717	48.74767	0.531	0.449333	1.109333	0.07405
41	WPSO5	S	43.265	52.83833	0.6955	0.949333	1.586833	0.0691
42	WP9	S	22.60583	54.86267	1.098467	1.713167	3.088667	0.189533
43	WS3	S	29.5695	47.0645	0.489833	0.540417	1.266667	0.1039
44	WPSO9	S	39.3895	51.25583	0.740167	1.279217	2.305317	0.085733
45	WESO4	S	32.76367	57.31733	0.491	0.492	0.95155	0.06385
46	W21	S	29.29935	56.11792	0.519333	0.416	0.896	0.07765
47	WE2	S	35.511	35.00433	0.655217	0.814167	1.361667	0.075833
48	WP8	S	18.01517	55.27607	0.780167	1.412	2.804167	0.149317
49	W16	S	24.7425	55.54383	0.490583	0.335667	0.868667	0.071083
50	WP7	S	21.6705	54.2229	1.345333	2.61	4.7295	0.218
51	WS3	S	45.19467	45.19467	0.91965	0.674333	2.7785	0.051117
52	WPE5	S	46.84483	44.75667	0.721133	0.536833	1.300333	0.053817
53	WPSE1	S	42.4185	48.8826	0.945333	0.7735	1.751833	0.051567
54	W15	S	25.616	53.79617	0.430083	0.328267	0.767167	0.0605
55	WPSO3	S	34.7515	55.5125	0.525667	0.5441	1.099967	0.058033
56	WPE4	S	48.27333	45.12343	0.810883	0.523883	1.380667	0.05485
57	WPSO2	S	34.12833	50.36833	0.54865	0.7535	1.402433	0.058833
58	W14	S	25.64127	54.86383	0.455867	0.339083	0.753717	0.0742
59	WP6	S	18.68317	54.0565	0.8417	1.083167	2.8265	0.12385
60	W20	S	24.635	57.61167	0.886167	0.53235	1.597	0.0953
61	WPSO8	S	1.19	54.63617	0.637883	0.693283	1.33585	0.058412
62	WE3	S	35.09263	47.29952	0.80045	0.850633	1.456083	0.0821
63	W22	S	12.3614	58.61517	0.540217	0.367633	1.020933	0.071667
64	WPE1	S	41.50922	48.86735	0.82905	1.183383	1.7567	0.715117
65	WPE6	S	41.30388	56.00872	0.991667	0.7346	1.77475	0.262607
66	E1	S	17.3592	66.38555	0.55195	0.4936	1.14745	0.107518
67	E2	S	17.63795	61.47275	0.4705	0.2784	0.72115	0.091316
68	E3	S	11.3454	64.1599	0.49705	0.30595	0.8894	0.060492
69	E4	S	15.44885	64.00595	0.5563	0.58915	1.1311	0.072994
70	E5	S	12.09605	66.6248	0.6078	0.3952	1.2916	0.075681
71	E6	S	16.1077	62.6836	0.5689	0.3375	0.9938	0.064699
72	E7	S	15.81275	63.9723	0.59595	0.40515	1.05245	0.036017
73	E8	S	13.6928	62.10125	0.46305	0.5249	1.0049	0.087677
74	E9	S	9.70845	71.70825	0.6382	0.40465	0.97335	0.07992
75	E10	S	11.7565	66.1188	0.63895	0.47405	1.25325	0.090001
76	E11	S	12.4255	65.41145	0.98915	0.59805	1.9781	0.149888
77	E12	S	8.87905	60.35475	0.4621	0.83495	1.37325	0.126807
78	E13	S	21.37905	62.71115	0.30565	0.2894	0.47365	0.084102

A. Kawabata Test Result for 113 Fabric Samples (Continued)

Code	Fabriccode	Enduse	WT	RT	G	HG	HG5	B
79	E14	S	12.23915	57.90385	0.55725	0.8967	1.7567	0.12565
80	E15	S	9.1683	70.23129	0.68585	0.5825	1.2548	0.062437
81	E16	S	10.5649	54.70605	0.4175	0.54985	1.26995	0.084109
82	E17	S	9.8642	64.7837	0.74365	0.48425	1.5155	0.066603
83	E18	S	11.6374	63.4165	0.5889	0.58695	1.4591	0.06414
84	KF1	K	17.45083	60.56823	0.76305	1.784967	1.901167	0.071533
85	KF2	K	17.34583	59.9113	1.339617	2.3848	3.0403	0.165417
86	KF3	K	19.22817	39.90495	1.06135	2.399983	2.759367	0.055533
87	KF4	K	20.10833	30.40959	0.9929	1.853983	2.025317	0.107883
88	KF5	K	12.80417	43.7586	0.976033	1.78004	2.423267	0.153417
89	KF6	K	13.6875	31.77917	1.4695	3.2825	3.6355	0.169417
90	KF7	K	16.5	30.46242	1.002017	1.574683	3.903683	0.1866
91	KF8	K	23.7075	35.07567	0.815	1.878967	1.946783	0.160877
92	KF9	K	10.29167	37.37233	0.758333	2.045233	2.34685	0.1771
93	KF10	K	19.39167	26.75383	0.793817	1.500533	1.663333	0.216317
94	KF11	K	14.1375	44.12933	0.627733	1.7138	1.790083	0.150117
95	KF12	K	54.23515	35.98648	2.62195	4.962917	6.78875	0.08265
96	KF13	K	49.73097	36.95473	1.931767	2.917683	4.043717	0.253433
97	KW1	K	15.91018	45.93205	4.5733	8.712367	11.73945	0.120983
98	KW2	K	16.78263	46.53767	3.145483	6.4286	7.0664	0.094667
99	KW3	K	22.01515	45.93205	4.30985	8.8481	4.653633	0.08965
100	KW4	K	11.72882	50.90342	3.72065	4.992283	8.050133	0.163067
101	KW5	K	26.53917	45.6972	3.741267	7.295083	6.000983	0.055383
102	KW6	K	24.01415	47.10203	2.461167	3.653083	4.342917	0.077317
103	KW7	K	16.89183	47.97333	3.089383	4.1875	5.873167	0.061683
104	KW8	K	12.39582	53.81957	3.3729	4.70225	6.247483	0.063167
105	KW9	K	12.65722	52.64568	3.52135	4.067117	6.0831	0.060533
106	KW10	K	15.15478	46.51996	4.027567	8.187417	8.629467	0.0922
107	KW11	K	23.62192	39.84883	4.41365	8.9543	9.894483	0.126983
108	KW12	K	13.96733	40.77634	3.601333	7.607417	8.161	0.108933
109	KW13	K	14.12027	48.059	3.71455	4.872317	7.057917	0.049683
110	KW14	K	23.12633	43.67993	2.877583	5.31815	5.89805	0.052308
111	KW15	K	16.17742	48.68238	3.659167	5.262833	6.8914	0.149617
112	KW17	K	22.10708	34.45703	4.7734	10.04503	11.06398	0.139083
113	KW18	K	24.74583	28.74417	1.038985	1.545267	1.757217	0.155933

A. Kawabata Test Result for 113 Fabric Samples (Continued)

Code	Fabriccode	Enduse	HB	MIU	SMD	MMD
1	W13	S	0.020406	0.1839	2.239667	0.021233
2	WPE3	S	0.0265	0.2074	2.633	0.023183
3	W3	S	0.025698	0.203883	4.327667	0.023767
4	WP4	S	0.03833	0.200167	4.450483	0.038233
5	w7	S	0.027867	0.179	3.85045	0.0219
6	W11	S	0.02675	0.228667	4.92845	0.026717
7	W10	S	0.029967	0.228	6.045667	0.041417
8	WN2	S	0.032725	0.222	4.4	0.03895
9	WS1	S	0.034887	0.211333	3.037167	0.031483
10	WP1	S	0.055517	0.191967	4.311	0.02125
11	W2	S	0.056101	0.2058	5.1725	0.024817
12	WE1	S	0.035173	0.20185	4.641667	0.025948
13	WPSO1	S	0.023217	0.204883	3.133833	0.022483
14	W8	S	0.0195	0.194283	3.260833	0.024217
15	WN1	S	0.0284	0.21971	2.3105	0.024367
16	WP2	S	0.022373	0.184	4.494667	0.029417
17	WPV1	S	0.0496	0.193117	8.316167	0.022583
18	W12	S	0.014293	0.197667	3.707	0.024233
19	WPE2	S	0.02452	0.187367	2.589167	0.016033
20	WC1	S	0.103417	0.203583	2.723667	0.020117
21	WPT1	S	0.036612	0.1949	2.305	0.023067
22	W4	S	0.022	0.173083	2.601333	0.026467
23	W6	S	0.023117	0.2026	2.705833	0.026683
24	W5	S	0.019725	0.180683	2.1395	0.021467
25	WPPT1	S	0.113947	0.173267	2.6625	0.020033
26	WP3	S	0.034665	0.2	4.526167	0.042467
27	WP5	S	0.01765	0.224617	8.47455	0.059783
28	W9	S	0.063283	0.22965	2.362833	0.025345
29	WS2	S	0.020217	0.21025	3.286167	0.02665
30	WM1	S	0.233422	0.226833	8.266667	0.032917
31	W1	S	0.042133	0.178517	5.153	0.02095
32	WP10	S	0.0388	0.17245	2.2005	0.014228
33	WPSO7	S	0.0332	0.170483	3.190833	0.01815
34	WPSO6	S	0.018477	0.167083	2.739167	0.01755
35	WE4	S	0.05975	0.172683	5.109167	0.02521
36	WPE7	S	0.026867	0.15595	6.994667	0.042233
37	WPSE3	S	0.022617	0.180317	3.287483	0.016662
38	W19	S	0.027067	0.168267	2.974	0.016778
39	W18	S	0.030883	0.175383	1.8815	0.055482

A. Kawabata Test Result for 113 Fabric Samples (Continued)

Code	Fabriccode	Enduse	HB	MIU	SMD	MMD
40	W17	S	0.017267	0.165667	2.043667	0.016517
41	WPSO5	S	0.024592	0.185583	2.937	0.021833
42	WP9	S	0.100367	0.209417	2.336667	0.031233
43	WS3	S	0.036217	0.214633	3.150833	0.03005
44	WPSO9	S	0.042083	0.195283	2.186167	0.0188
45	WESO4	S	0.015683	0.198983	2.648333	0.025263
46	W21	S	0.02175	0.220617	3.5316	0.0293
47	WE2	S	0.0264	0.198633	2.850167	0.017983
48	WP8	S	0.067733	0.21935	3.666667	0.21935
49	W16	S	0.014683	0.189283	4.099667	0.189283
50	WP7	S	0.129167	0.214367	2.717617	0.214367
51	WS3	S	0.016083	0.185183	5.849833	0.04645
52	WPE5	S	0.0137	0.179217	4.791167	0.027883
53	WPSE1	S	0.017833	0.188917	4.881833	0.0427
54	W15	S	0.012833	0.18575	2.011	0.0192
55	WPSO3	S	0.018167	0.1911	4.797333	0.02765
56	WPE4	S	0.01585	0.184083	4.638833	0.0253
57	WPSO2	S	0.019017	0.194983	3.7475	0.023632
58	W14	S	0.019167	0.209517	4.108833	0.064733
59	WP6	S	0.05395	0.21695	11.321	0.047183
60	W20	S	0.0208	0.199933	3.094667	0.033867
61	WPSO8	S	0.018625	0.177167	2.5765	0.01815
62	WE3	S	0.02965	0.190117	2.124167	0.017117
63	W22	S	0.015417	0.202917	2.628333	0.02695
64	WPE1	S	0.28365	0.2511	5.3735	0.029683
65	WPE6	S	0.030017	0.174288	6.619	0.047317
66	E1	S	0.02771	0.231348	0.062884	8.9498
67	E2	S	0.016486	0.203336	0.016494	2.1939
68	E3	S	0.015243	0.158984	0.017057	2.76525
69	E4	S	0.020109	0.194292	0.018392	3.35135
70	E5	S	0.013912	0.184131	0.018413	2.17795
71	E6	S	0.014913	0.165209	0.014936	1.9236
72	E7	S	0.021042	0.178274	0.019083	2.23105
73	E8	S	0.022333	0.175708	0.023006	3.642415
74	E9	S	0.020127	0.174409	0.043833	5.4553
75	E10	S	0.024138	0.187167	0.026966	2.55385
76	E11	S	0.044041	0.136215	0.020437	1.81195
77	E12	S	0.059471	0.207765	0.025183	11.24155
78	E13	S	0.018033	0.237356	0.041612	7.30865

A. Kawabata Test Result for 113 Fabric Samples (Continued)

Code	Fabriccode	Enduse	HB	MIU	SMD	MMD
79	E14	S	0.044144	0.180998	0.019563	2.10165
80	E15	S	0.01825	0.221426	0.04514	5.9357
81	E16	S	0.031605	0.219653	0.0411	6.4119
82	E17	S	0.018342	0.157466	0.013191	1.4826
83	E18	S	0.018554	0.194081	0.042827	8.802922
84	KF1	K	0.068065	0.225015	0.023983	2.68785
85	KF2	K	0.154833	0.102057	0.017612	2.526962
86	KF3	K	0.17585	0.360243	0.100273	5.00221
87	KF4	K	0.08875	0.208517	0.1233	2.9388
88	KF5	K	0.117483	0.194033	0.021225	2.271517
89	KF6	K	0.132883	0.221967	0.02732	5.25983
90	KF7	K	0.054817	0.19734	0.022165	2.78775
91	KF8	K	0.188465	0.324793	0.04304	4.6891
92	KF9	K	0.087883	0.2001	0.026333	3.045883
93	KF10	K	0.2143	0.271833	0.036443	4.326445
94	KF11	K	0.175917	0.273617	0.027846	3.556867
95	KF12	K	0.07015	0.192893	0.02613	1.192917
96	KF13	K	0.162417	0.181878	0.024772	2.382967
97	KW1	K	0.15235	0.376783	0.019492	3.46325
98	KW2	K	0.08935	0.255048	0.015287	6.694867
99	KW3	K	0.119333	0.358798	0.082035	4.573
100	KW4	K	0.058717	0.204022	0.037789	2.42415
101	KW5	K	0.0721	0.221842	0.013135	5.502267
102	KW6	K	0.10165	0.238648	0.022185	2.124707
103	KW7	K	0.06425	0.24855	0.029442	2.9407
104	KW8	K	0.066883	0.224527	0.010583	1.974088
105	KW9	K	0.053328	0.223398	0.010585	2.120117
106	KW10	K	0.12405	0.310637	0.034487	2.684967
107	KW11	K	0.130367	0.378453	0.02569	3.6795
108	KW12	K	0.2378	0.275933	0.023379	6.178967
109	KW13	K	0.04825	0.242625	0.014938	2.40295
110	KW14	K	0.0707	0.269977	0.01119	1.703583
111	KW15	K	0.077883	0.213911	0.0266	2.080117
112	KW17	K	0.180833	0.283633	0.017116	5.246417
113	KW18	K	0.11925	0.285975	0.047917	7.477993

B. Kawabata's Primary Hand and Total Hand Value

Code	Fabric code	Enduse	KOSHI	NUMERI	FUKURAMI	THV
1	W13	S	6.04725	4.56331	3.072746	2.71598
2	WPE3	S	3.822573	4.029463	3.589153	2.350679
3	W3	S	2.934654	5.942782	5.942772	3.197825
4	WP4	S	6.375774	1.990579	1.684298	1.626928
5	w7	S	6.237368	4.3367	2.969284	2.614695
6	W11	S	2.765267	5.215394	5.032798	2.739218
7	W10	S	5.472372	1.87145	1.695899	1.561567
8	WN2	S	6.23731	2.010702	1.647383	1.60682
9	WS1	S	3.677937	3.686555	3.448964	2.179242
10	WP1	S	1.819946	6.117332	5.877497	2.85889
11	W2	S	1.051609	5.975612	6.685461	2.428337
12	WE1	S	3.395283	5.125643	5.19517	2.921507
13	WPSO1	S	3.96636	4.490004	3.513038	2.512435
14	W8	S	5.119652	3.817724	3.108506	2.403882
15	WN1	S	4.986087	4.727735	3.986853	2.915976
16	WP2	S	4.879886	3.178223	2.607311	2.042515
17	WPV1	S	5.485458	3.131652	3.266975	2.334461
18	W12	S	4.813012	4.135268	3.277521	2.501415
19	WPE2	S	3.800222	5.417649	4.799563	3.105846
20	WC1	S	7.167921	3.988484	3.715643	2.72554
21	WPT1	S	6.04087	2.972538	2.112432	1.933837
22	W4	S	5.447002	3.755986	2.71155	2.293978
23	W6	S	5.519572	3.622485	2.935926	2.344652
24	W5	S	5.861679	4.462516	3.116515	2.683017
25	WPPT1	S	6.626737	4.146903	3.844362	2.814769
26	WP3	S	8.531419	1.338496	1.355413	1.292081
27	WP5	S	5.14331	-0.25483	-0.0703	0.630479
28	W9	S	5.14171	3.656742	2.509237	2.155894
29	WS2	S	4.483041	4.255582	3.471896	2.53593
30	WM1	S	5.557095	3.79154	5.234315	2.895178
31	W1	S	2.815258	6.238685	6.367821	3.311977
32	WP10	S	6.641553	5.548604	4.163134	3.419743
33	WPSO7	S	4.0067	5.567153	3.914203	3.054232
34	WPSO6	S	4.798253	5.240212	3.55526	2.980016
35	WE4	S	4.14398	4.610988	3.933197	2.703247

B. Kawabata's Primary Hand and Total Hand Value (Continued)

Code	Fabric code	Enduse	KOSHI	NUMERI	FUKURAMI	THV
36	WPE7	S	6.805948	1.287666	1.698199	1.603242
37	WPSE3	S	4.538354	5.65764	4.659853	3.357066
38	W19	S	5.596302	4.817209	3.541614	2.913003
39	W18	S	4.49758	2.408629	1.840253	1.533813
40	W17	S	5.074883	6.030779	4.327448	3.567651
41	WPSO5	S	4.609975	4.577676	3.848741	2.766567
42	WP9	S	8.046685	2.069962	2.100945	1.741233
43	WS3	S	4.975246	3.345998	2.910885	2.200693
44	WPSO9	S	4.927131	4.795175	4.10514	2.95829
45	WESO4	S	4.412896	4.334028	3.432256	2.536157
46	W21	S	5.039229	3.578515	3.339086	2.400444
47	WE2	S	3.509706	6.816576	6.82431	3.832028
48	WP8	S	7.205553	-4.45093	-2.1093	0.740261
49	W16	S	5.512596	-2.64983	-1.28054	0.477057
50	WP7	S	9.266671	-4.81176	-2.38727	0.437545
51	WS3	S	5.475413	1.148061	1.700258	1.538572
52	WPE5	S	4.639041	4.050621	3.698653	2.56314
53	WPSE1	S	5.447276	1.94712	2.107444	1.745439
54	W15	S	4.270817	5.782802	4.187231	3.274756
55	WPSO3	S	4.088482	3.734236	3.161492	2.208015
56	WPE4	S	4.773021	4.209082	3.773029	2.653968
57	WPSO2	S	4.305	4.072919	3.060223	2.319228
58	W14	S	5.181748	1.105939	1.17419	1.247539
59	WP6	S	7.189749	-0.2722	0.502993	1.077881
60	W20	S	7.209686	2.179735	2.119231	1.82865
61	WPSO8	S	6.086111	4.145058	0.920767	1.65567
62	WE3	S	4.677466	6.191112	5.714119	3.757683
63	W22	S	5.490088	3.74936	2.503047	2.220131
64	WPE1	S	10.99682	1.532409	1.724107	0.8054
65	WPE6	S	9.529448	0.447697	1.60708	1.233312
66	E1	S	5.875358	-0.36713	1.412241	1.5601
67	E2	S	5.731787	5.564624	4.707614	3.48602
68	E3	S	4.341941	5.897807	5.272857	3.511724
69	E4	S	3.833642	5.368477	5.531026	3.172857
70	E5	S	6.545815	4.161771	3.373951	2.693115
71	E6	S	5.122526	6.24068	5.293395	3.822338
72	E7	S	2.917468	5.719115	4.920084	3.000097
73	E8	S	4.734168	4.582156	4.535983	2.933059

B. Kawabata's Primary Hand and Total Hand Value (Continued)

Code	Fabric code	Enduse	KOSHI	NUMERI	FUKURAMI	THV
74	E9	S	4.962203	2.127069	3.56184	2.199665
75	E10	S	5.937362	3.792054	4.098326	2.745529
76	E11	S	7.887038	4.228029	3.983995	2.810446
77	E12	S	4.740644	3.019814	3.482392	2.271159
78	E13	S	3.470445	2.646308	3.537899	1.932401
79	E14	S	5.726281	4.98577	4.816443	3.256378
80	E15	S	3.882179	0.562194	1.299017	1.081914
81	E16	S	4.719832	1.837154	2.583574	1.82176
82	E17	S	6.228643	6.085116	4.856454	3.789671
83	E18	S	4.538509	1.26162	2.343803	1.674507
84	KF1	S	2.570011	-8.47066	-4.36364	1.01015
85	KF2	S	5.612941	-7.65129	-3.55492	1.761551
86	KF3	S	-1.26309	-10.2427	-3.4222	1.861409
87	KF4	S	3.277926	-9.06166	-5.45855	0.616967
88	KF5	S	4.63069	-7.57364	-4.15226	0.944731
89	KF6	S	6.155252	-11.4452	-7.68326	1.049082
90	KF7	S	5.262699	-9.20474	-5.34345	1.329149
91	KF8	S	1.405804	-9.74011	-3.93118	2.329637
92	KF9	S	4.597588	-8.82674	-5.50757	0.634041
93	KF10	S	2.156952	-8.88955	-3.79702	1.870573
94	KF11	S	1.758826	-8.75572	-4.01059	1.346849
95	KF12	S	4.328958	-5.68878	-1.02082	2.163333
96	KF13	S	6.547409	-7.32178	-2.00278	2.934015
97	KW1	S	6.248593	-11.3336	-4.54684	4.829212
98	KW2	S	6.454633	-12.6775	-6.70072	4.079707
99	KW3	S	4.299073	-11.609	-4.54314	4.948834
100	KW4	S	7.541833	-9.26069	-3.40623	3.52879
101	KW5	S	2.285172	-10.536	-4.29554	3.254045
102	KW6	S	1.400361	-6.64463	-0.69763	2.131358
103	KW7	S	4.01138	-9.33133	-3.75375	2.974193
104	KW8	S	3.662191	-7.19142	-2.14066	2.30011
105	KW9	S	3.784145	-7.56006	-2.41645	2.419885
106	KW10	S	5.476696	-10.4948	-4.72941	3.524078
107	KW11	S	6.135448	-11.4128	-4.54163	4.932458
108	KW12	S	4.890718	-11.6526	-4.69538	4.948697
109	KW13	S	3.255464	-8.25972	-2.89895	2.493985
110	KW14	S	1.262513	-6.19577	-0.96065	1.525836
111	KW15	S	6.712842	-8.19449	-2.69137	3.141803
112	KW17	S	7.122347	-11.8202	-5.3583	4.551829
113	KW18	S	3.332833	-12.041	-6.93438	2.385467

C. Neural Network Output

Code	Fabric Code	Hand Index
38	W19	0.965687
15	WN1	0.850715
12	WE1	0.925752
73	E8	0.9243
96	KF13	0.292593
44	WPSO9	0.383398
103	KW7	0.268595
34	WPSO6	0.923878
72	E7	0.323072
33	WPSO7	0.670832
19	WPE2	0.347074
111	KW15	0.339919
69	E4	0.308581
3	W3	0.239052
101	KW5	0.271782
79	E14	0.292443
54	W15	0.277696
31	W1	0.883598
37	WPSE3	0.23797
32	WP10	0.892302
67	E2	0.442633
68	E3	0.277179
106	KW10	0.328438
100	KW4	0.598702
40	W17	0.290364
62	WE3	0.267847
82	E17	0.882703
71	E6	0.431821
47	WE2	0.865413
98	KW2	0.262169
112	KW17	0.277786
97	KW1	0.262894
107	KW11	0.254399
108	KW12	0.174392
99	KW3	0.251492
50	WP7	0.18432
49	W16	0.280866
87	KF4	0.333149
27	WP5	0.248807
92	KF9	0.272794
48	WP8	0.563319
88	KF5	0.275385
84	KF1	0.368858
89	KF6	0.273759
59	WP6	0.504396
80	E15	0.557982
65	WPE6	0.381584
58	W14	0.906584

D. KN-101-WINTER Equation Constant Coefficient

(a) X_i, X_i σ_i table

Block	i	$\overline{X\iota}$	WINTER SUIT N=214 $\overline{X\iota}$	σ_i
	0			
1	1	LT	0.6082	0.0611
	2	log WT	0.9621	0.1270
	3	RT	62.1894	4.4380
2	4	log B	-1.0084	0.1267
	5	log 2HB	-1.3476	0.1801
3	6	log G	-0.0143	0.1287
	7	log 2HG	0.0807	0.1642
	8	log 2HG5	0.4094	0.1441
4	9	log LC	0.3703	0.0745
	10	log WC	-0.7080	0.1427
	11	log RC	56.2709	8.7927
5	12	MIU	0.2085	0.0215
	13	log MMD	-1.8105	0.1233
	14	log SMD	0.6037	0.2063
6	15	log T	-0.1272	0.0797
	16	log W	1.4208	0.0591

(b) C_i Table

KOSHI			NUMERI			FUKURAMI		
i	C_i	R	i	C_i	R	i	C_i	R
0	5.7093		0	4.7533		0	4.9799	
4	0.8459	0.740	13	-0.9270	0.595	10	0.8845	0.600
5	-0.2104	0.780	14	-0.3031	0.633	9	-0.2042	0.616
6	0.4268	0.849	12	-0.1539	0.645	11	0.1879	0.639
7	-0.0793	0.854	10	0.5278	0.734	13	-0.5964	0.754
8	0.0625	0.854	9	-0.1703	0.742	14	-0.1702	0.768
15	-0.1714	0.868	11	0.0972	0.749	12	-0.0569	0.770
16	0.2232	0.889	8	-0.3702	0.794	1	-0.1558	0.782
2	-0.1345	0.896	6	-0.0263	0.794	2	0.2241	0.793
3	0.0676	0.898	7	0.0667	0.792	3	-0.0897	0.795
1	-0.0317	0.899	4	-0.1658	0.807	8	-0.0657	0.799
10	-0.646	0.900	5	0.1083	0.803	6	0.0960	0.800
9	0.0073	0.900	1	-0.0686	0.808	7	-0.0538	0.802
11	-0.0041	0.901	3	-0.1619	0.812	15	-0.0837	0.807
13	0.0307	0.901	2	0.0735	0.813	16	-0.1810	0.805
12	-0.0254	0.901	16	-0.0122	0.813	5	0.0848	0.805
14	0.0009	0.901	15	-0.1358	0.812	4	-0.0337	0.806

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